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INSECTICIDES FOR THE CONTROL OF INSECTS OF PUBLIC HEALTH IMPORTANCE

Harry D. Pratt, et al

Communicable Disease Center
Atlanta, Georgia

1962

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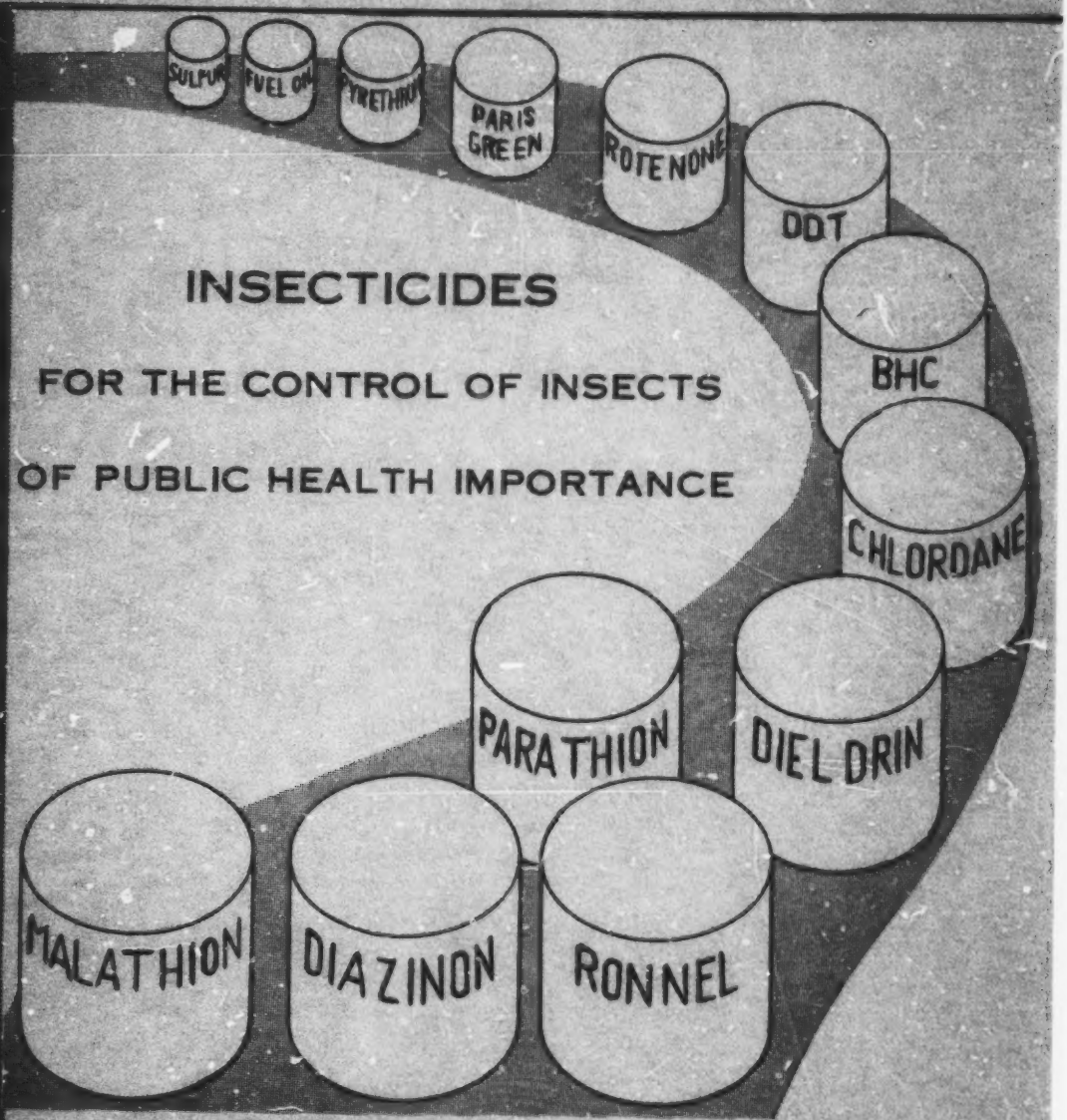

INSECTICIDES

FOR THE CONTROL OF INSECTS OF PUBLIC HEALTH IMPORTANCE

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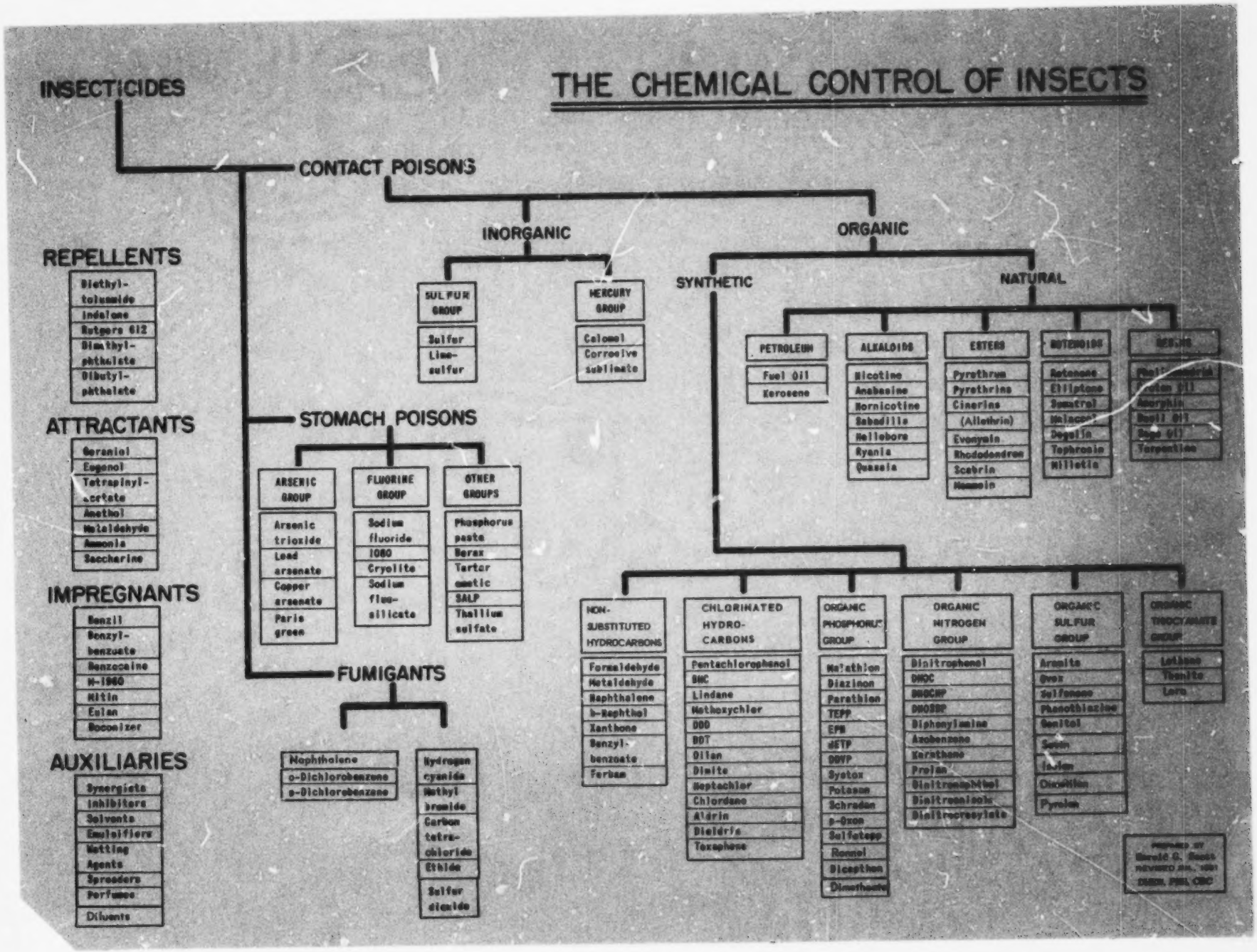

INSECTICIDES

FOR THE CONTROL OF INSECTS OF PUBLIC HEALTH IMPORTANCE

Training Guide — Insect Control Series

HARRY D. PRATT – KENT S. LITTIG

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INTRODUCTION

The many programs for the control of vector-borne diseases have led to a tremendous evolution in insecticides during the past sixty years. In 1900 public health workers relied on arsenicals, sulfur, petroleum oils, and pyrethrum. During World War I, hydrocyanic gas and mercury preparations were used in vermin control. In the period between World Wars I and II, the fluorine compounds were added to the inorganic and rotenone to the botanical insecticides, paris green came into world-wide usage as a mosquito larvicide, and the dinitro and thiocyanate compounds were tested as synthetic organic compounds. World War II saw the rise of the chlorinated hydrocarbons, DDT originating in Switzerland, and BHC in Great Britain and France. Following World War II other, more toxic chlorinated hydrocarbon insecticides made their appearance: chlordane, toxaphene, dieldrin, and aldrin. As the result of research in Germany during World War II, a new group of powerful insecticides, the organophosphorus compounds, were introduced in the late 1940's including such highly toxic materials as TEPP and parathion. Later, less toxic, broad spectrum, organophosphorus insecticides such as malathion, Diazinon, and ronnel were tested and adopted by public health workers. In recent years much attention has been given to the problem of pesticide residues in foods. As a result increasing attention has been devoted to synergists for the older, safer botanicals, such as pyrethrum and rotenone, and also to certain of the organic phosphorus, carbamate and other insecticides which leave minimum residues on foods.

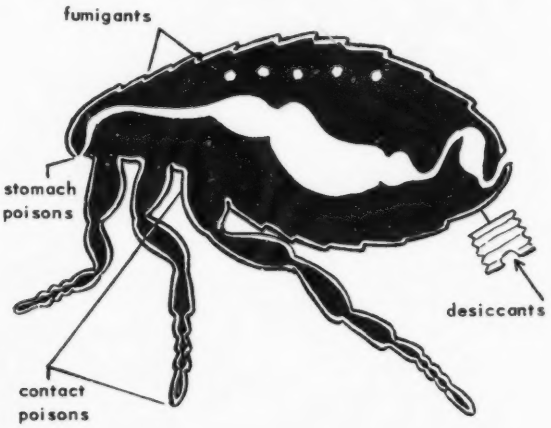
Correlated with this development of new insecticides, there has been a revolution in the technology of using these chemicals. At the beginning of the twentieth century insecticides were used as simple stomach poisons, contact sprays or fumigants. Today, in addition to these formulations, there are modifications such as aerosols, residual sprays and fumigants, fly cords, and sorptive dusts.

Many insecticides are toxic to humans, domesticated animals, and wildlife and must be used with unremitting care. These chemicals are costly and should be applied in the most economical and effective manner. Moreover, one must consider whether or not chemical control of the insect is the most satisfactory answer to the problem. Flies, for example, may be controlled to a great extent by sanitation, by means of screens, and by other methods that will improve the general level of human standards of living. Insecticides have to be used repeatedly in order to maintain control. Chemical control should supplement – not supplant – other control activities.

It is the purpose of this Training Guide to give a brief introduction to the insecticides of interest to public health workers and to the ways they may be prepared for use.

WAYS IN WHICH INSECTICIDES ARE USED

An **insecticide** is a substance employed to kill insects. An ideal insecticide should kill insects and arachnids quickly and be harmless to vertebrate animals. It should be cheap, available in large quantities, chemically stable, non-inflammable, easily prepared, non-corrosive, non-staining, and have no unpleasant odor. At present there is no such perfect material, not even DDT. Insecticides are often classified according to their mode of entry into the insect body as stomach poisons, contact poisons, fumigants and desiccants. **Stomach poisons** must be swallowed to cause death. **Contact poisons** penetrate the body wall, frequently through the tarsi, as the insect rests on a surface covered with a residual insecticide. **Fumigants** are volatile chemicals whose vapors enter the insect through the breathing pores, known as spiracles, and the body surfaces. **Desiccants** are dusts which scratch, abrade, or absorb the fatty, water-resistant outer layer on the insect exoskeleton, causing the insect to lose body fluids and die by dehydration.



Some insecticides, such as chlordane, can kill insects in several ways, by acting as either a stomach poison, a contact insecticide, or a fumigant. Therefore, another terminology has been used by many entomologists, based on the stage of the insect on which the insecticide acts: **ovicides**, which kill insect eggs; **larvicides**, directed against the immature stages of insects, whether larvae or nymphs; and **adulticides**, for the control of adult insects. There are many other terms such as **acaricides** or **miticides** for killing mites, or **pediculicides** or **lousicides** for killing lice. Some of these terms are rather difficult to justify. For this reason, many public health entomologists prefer the following classification of insecticides:

ADULTICIDES	LARVICIDES
Space Sprays	Solutions
Aerosols	Emulsions
Fogs	Suspensions
Mists	Dusts
Residual Sprays	Granules
Fumigants	
Dusts	
Fly Cords	
Insect Baits	
Sorptive Dusts	
Insecticidal Resins	

Some materials emit odors that repel or attract insects. Dimethyl phthalate, a repellent, is applied to clothing and exposed skin surfaces to prevent attack by mosquitoes and other insects. Moths are repelled from clothing treated with the silicofluorides. Repellents do not necessarily kill insects but they do protect people and materials from insect attack. Attractants, as the name implies, attract insects, and are used to induce insects either to enter a trap or to feed upon a poison bait.

TYPES OF INSECTICIDES

In this Training Guide an attempt has been made to retain the traditional three-fold division into CONTACT INSECTICIDES, STOMACH POISONS, and FUMIGANTS and the subgroupings as diagrammed on the chart on the inside front cover. Within these broad groups, the subgroupings follow the broad concepts of Frear (1955) and Kenaga (1960). The contact insecticides are divided into organic and inorganic compounds, and the former into synthetic organic compounds and natural organic materials such as the botanicals and petroleum oils. At the present time the most widely used, generally available chemicals employed in the control of insects of public health importance are the synthetic organic insecticides. Two of the most important groups of these insecticides, the

chlorinated hydrocarbon and organic phosphorus compounds will be discussed first because these materials are being studied now and are used much more both in the laboratory and in the field than are the older inorganic chemicals.

CONTACT INSECTICIDES

SYNTHETIC ORGANIC INSECTICIDES

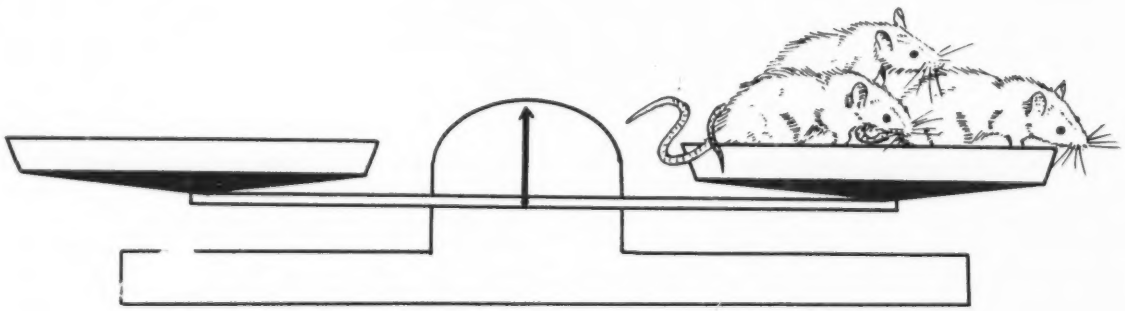
These insecticides vary greatly in their toxicity to man, from very toxic materials such as TEPP, parathion, and endrin to relatively safe compounds such as malathion and methoxychlor. Hayes (1960) has written "The **hazard** of a given compound is the danger which it presents; the **toxicity** of a compound is its inherent ability to injure living organisms. Hazards may be measured only in relation to practical conditions, although it can be predicted, to a limited extent, from toxicity. Conversely, toxicity may be guessed from the results of accidents; but, unless the dosage involved in such accidents is known accurately, toxicity can be measured only under standardized experimental conditions." Using white rats as standard test animals, two main types of laboratory experiments have been devised to determine the relative toxicities of these insecticides. In one method, to determine the reaction when swallowed by mouth, or the **oral toxicity**, the insecticides are dissolved in peanut oil and given orally by means of a stomach tube. In the second method, to determine the reaction when absorbed through the skin, or the **dermal toxicity**, the chemicals are dissolved in xylene and applied to the skin on the backs of shaved laboratory animals, often rats. The toxicity in both cases is expressed as a number of parts of insecticide necessary to kill a million parts of the test animal. For ease in calculating these dosages, the metric system is used since one million milligrams equals one kilogram.

1000 milligrams = 1 gram
1000 grams = 1 kilogram

1,000,000 milligrams = 1 kilogram

mg./kg.

Milligrams of insecticide needed to kill 1 kilogram of test animal



1 kilogram = 2.2 lbs.
= 36 ounces
= weight of three 12-ounce rats

The LD_{50} is the **lethal dose** of insecticide (expressed as mg. of poison per kg. of body weight) that is required to kill at least 50 percent of a group of test animals, hence LD_{50} values are often expressed as "mg./kg."

The oral LD_{50} and the dermal LD_{50} values of a given insecticide are rarely the same. In comparing two insecticides, the acute oral and dermal toxicity values are sometimes reversed as shown in the studies on female white rats by Gaines (1960) listed below:

Insecticide	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)
Chlordane	430	530
DDT	118	2510

These data indicate that it takes more chlordane than DDT to kill 50 percent of the white rats when swallowed by mouth, while it takes more DDT than chlordane to kill 50 percent of these same animals if the insecticides are absorbed through the skin.

Gaines (1960) has discussed this relationship in some detail as follows: "A comparison of the laboratory results and use experience indicates that there is a much closer relationship between dermal LD_{50} values and the occurrence of occupational poisoning. This is emphasized by a study of groups of compounds in which the oral toxicities are of similar magnitude but the dermal toxicities are significantly different." The data in Table 2.1 from Gaines (1960) illustrates these facts very well.

TABLE 2.1 RELATIONSHIP BETWEEN TOXICITY AND SAFETY OF PESTICIDES

Compounds	LD_{50} Values in Male Rats (Mg/kg)		Kind of Exposure Associated with Systemic Poisoning	Greatest Severity of Occupational Poisoning
	Oral	Dermal		
DDT	113	2510	Ingestion	–
Lindane	88	1000	Ingestion	–
Dieldrin	46	90	Ingestion and occupational	Severe
Methyl parathion	18	65	Occupational	Mild
Guthion	13	220	Occupational	Mild
Parathion	13	21	Ingestion and occupational	Severe
Thimet	2	6	Occupational	Severe
Phosdrin	6	5	Occupational	Severe

Over 100 cases of occupational poisoning by dieldrin have been reported (Hayes, 1959), and others are known to have occurred. By contrast, DDT and lindane, which are much less toxic by the dermal route (but have an oral toxicity of the same order of magnitude as dieldrin), are not known to have produced systemic occupational poisoning, although crude benzene hexachloride may be a source of dermatitis or mild systemic effects, and both compounds have produced poisoning when they were swallowed.

In a similar way, severe occupational poisoning has occurred with parathion, but not with methyl parathion or Guthion. A few cases of mild poisoning have followed occupational exposure to methyl parathion and Guthion, however, their limited use is not the only reason for their present record. Thimet and Phosdrin have had even more limited use, but both already have been the cause of severe occupational poisoning.

The insecticides may be divided into three groups based on their dermal toxicities as shown in Table 2.2. **The slightly toxic insecticides,** such as DDT, methoxychlor, malathion, and ronnel,

TABLE 2.2 CORRELATION BETWEEN RATIO OF DERMAL TOXICITY TO RATS AND STRENGTH OF INSECTICIDES RECOMMENDED AS RESIDUAL SPRAYS*

Insecticide	Approximate Ratio of Acute Dermal Toxicity to DDT	Acute Dermal Toxicity to Female Rats LD_{50} (mg/kg)	Recommended percent Insecticide in Residual Sprays
HIGHLY TOXIC INSECTICIDES – Acute dermal toxicity to rats 1-50 mg/kg			
TEPP	500	5	Not Recommended as Residual Sprays for Arthropods of of Public Health Importance
Thimet	1000	2.5	
Phosdrin	600	4.2	
Isolan	405	6.2	
Parathion	370	6.8	
Demeton	300	8.2	
Endrin	166	15	
Isodrin	110	23	
MODERATELY TOXIC INSECTICIDES – Acute dermal toxicity to rats 50-1000 mg/kg			
Dieldrin	42	60	0.625-1.25
Delnav	40	63	1.0
DDVP	33	75	0.5
Aldrin	25	98	0.5
Heptachlor	10	250	0.5-1.0
Nicotine sulfate	9	285	0.5-1.0
Diazinon	6	455	0.5-1.0
Chlordane	5	530	2.0-3.0
Toxaphene	3.1	780	
Lindane	2.8	900	0.5-1.0
SLIGHTLY TOXIC INSECTICIDES – Acute dermal toxicity to rats 1000-6000 mg/kg			
Kelthane	2.5	1000	
Dicapthon	2	1250	1.0
Chlorobenzilate			
Dipterex	1	2000	1.0
Lead arsenate	1	2400	
Paris green	1	2400	
Ronnel	–	–	1.0-2.0
DDT*	1	2510	5.0-10.0
Methoxychlor	0.4	>6000	5.0-10.0
Sevin	0.6	4000	5.0-10.0
Malathion	0.5	4444	5.0
Dilan	0.3	5900	5.0-10.0

* LD_{50} data to rats, largely from Gaines (1960).

are recommended as residual sprays both for interior and exterior surfaces of buildings and for many other types of applications. **The moderately toxic insecticides** such as chlordane, diazinon, and dieldrin, are generally recommended for spot applications indoors and as broad residual sprays or dusts outdoors. **The highly toxic insecticides** are widely used in agriculture but only under rather specialized conditions by public health workers, such as parathion-treated cords for fly control, aerial dispersal of parathion for mosquito control, or endrin sprays to reduce populations of wild rodents.

In the following discussion the synthetic organic insecticides will be discussed under four broad groupings: the chlorinated hydrocarbon insecticides, the organic phosphate insecticides, the organic thiocyanates, and the organic nitrate and sulfur groups.

CHLORINATED HYDROCARBON INSECTICIDES

The chlorinated hydrocarbon insecticides all contain chlorine, hydrogen, and carbon. Some of these compounds also contain other elements such as oxygen or sulfur. However, beyond this broad similarity, these compounds vary widely in their chemical structure and activity. Although much is known about the pharmacology of these materials, the basic mode of action is not known for a single one of them. Brown (1951) reported that some of these insecticides, such as DDT, act as a central nervous system poison in which the symptoms appear in four stages: excitation, convulsions, paralysis, and death.

The chlorinated hydrocarbon insecticides are grouped into several series of related compounds. When insects have developed resistance to one insecticide, entomologists have often changed to another compound in an entirely different series and achieved spectacular control. An outstanding example of this method was the change to 1 percent lindane powder to control DDT-resistant lice in Korea. In the United States, when entomologists found that German cockroaches were resistant to two chlorinated hydrocarbon insecticides, chlordane and lindane, good control was reported following the change to an organic phosphorus insecticide such as malathion or diazinon.

Some of the chlorinated hydrocarbon insecticides most commonly used by public health workers are listed in the Table 2.3 with acute dermal and oral LD_{50} values to laboratory white rats, largely as listed in Gaines (1960).

TABLE 2.3 TOXICITY OF SOME SELECTED CHLORINATED HYDROCARBON INSECTICIDES TO FEMALE LABORATORY RATS*

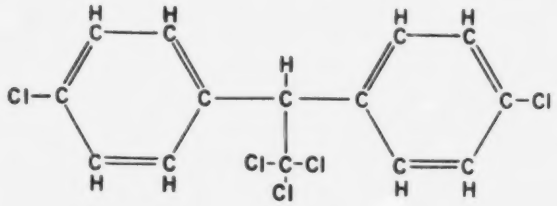
Insecticide	Acute Dermal LD_{50}	Acute Oral LD_{50}
DDT SERIES		
DDT	2510	118
DDD	Slightly Irritating	2500
Methoxychlor	–	6000
BENZENE HEXACHLORIDE SERIES		
Benzene Hexachloride (BHC)		
Lindane	900	91
CHLORDANE SERIES		
Chlordane	530	430
Heptachlor	250	162
Aldrin	98	60
Dieldrin	60	46
Endrin	15	7.5

* Data largely from Gaines (1960)

DDT Series

The insecticides in this DDT series include DDT, DDD, methoxychlor, DMC, perthane, chlorobenzilate, and kelthane (Kenaga, 1960).

DDT – $C_{14}H_9Cl_5$



The symbol DDT indicates the first three letters in the name of this remarkable insecticide: Dichloro-Diphenyl-Trichloroethane. More DDT is used in vector control than all other insecticides combined (Hayes, 1960). Although DDT was first described in 1874 by the German chemist, Othmar Zeidler, its insecticidal effectiveness was not discovered until about 1939 when Paul Muller determined its value in controlling the Colorado potato beetle and other insects in Switzerland. In 1942, samples were shipped to the United States for testing at the Orlando, Florida Laboratory of the U. S. Department of Agriculture. Here scientists determined that DDT was very effective as a contact insecticide against many insects of public health importance and also that it possessed remarkable residual qualities. During World War II, DDT was so important in controlling mosquitoes, flies, lice, fleas and bed bugs that over 9 million pounds were manufactured in 1944 and over 33 million pounds in 1945, almost the entire production being allocated for military use until August 31, 1945 (Shepard, 1951).

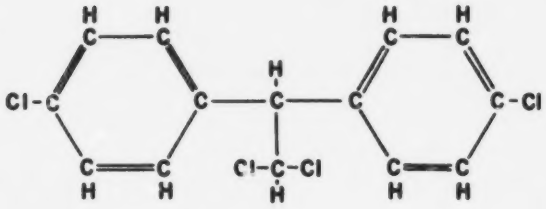
Paul Muller was awarded the Nobel Prize in Medicine in 1948 for his role in the discovery of DDT as an insecticide. The production of DDT has increased every year since 1942. In the crop year 1958-1959, some 156 million pounds of DDT were produced in the United States alone (Shepard, 1960).

Since 1942 DDT has produced a revolution in the technology of vector-borne disease control. This insecticide is one of the cheapest, most effective, long-lasting, all-purpose insecticides known. DDT is almost insoluble in water but is formulated as a dust, oil solution, emulsion concentrate, wettable powder, and aerosol spray. While resistance to DDT has developed in certain mosquitoes, this compound is still extensively used as a larvicide, for pre-hatch treatment of larval breeding areas, as a space spray, and as a residual spray. DDT is the most important insecticide used as a residual spray in the world-wide Malaria Eradication Program. In areas where there is no resistance, or where organic insecticides have not been used previously, DDT is usually the insecticide of choice for the control of flies, mosquitoes, lice, fleas, and bed bugs, because of its low cost, long life, availability, and ease of formulation and application. In many parts of the world, the house fly and its close relatives have developed resistance to DDT, but this material is still used in most areas for the control of blow flies and many other flies. Other insecticides, such as chlordane, lindane, malathion, and diazinon are superior to DDT for the control of cockroaches, ants, ticks, and mites. DDT has a good safety record. According to the "Clinical Memoranda on Economic Poisons," Communicable Disease Center, 1956, "There is no well-described case of fatal uncomplicated DDT poisoning in a human being." A number of deaths have been reported following the ingestion of DDT solutions. In these instances the clinical picture has frequently been characteristic of solvent poisoning, particularly the swallowing of kerosene. DDT should not be sprayed on corn or forage used to feed dairy cattle, nor used to control arthropods in dairy barns or on cattle, because it is stored in fat and does appear in milk as residues of DDT or its metabolite DDE.

Other compounds with structural formulae similar to DDT include DDD, methoxychlor, perthane, DMC, and Dilan. These chemicals have been used in controlling flies, mosquitoes, and other arthropods of public health importance. Some of these compounds, such as methoxychlor, have low mammalian toxicity and have been used as residual sprays in dairy barns, in food-handling establishments, for the control of ectoparasites, or for the control of insects (such as the Mexican bean beetle) with natural resistance to DDT. Others, such as DMC and perthane, may have a synergistic action when used in combination with organic insecticides such as DDT or malathion. Another group of compounds related to DDT includes chlorobenzilate and Kelthane. These are used in controlling mites.

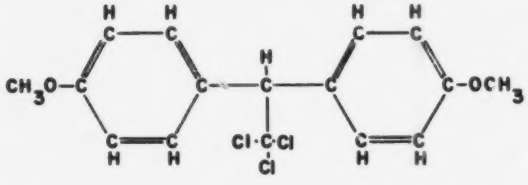
DDD (or TDE) or dichloro-diphenyl-dichloroethane is similar in action to DDT but exhibits less toxicity to fish and warm-blooded animals. DDD is also used to control larvae of chironomid midges and black flies.

DDD – $C_{14}H_{10}Cl_4$



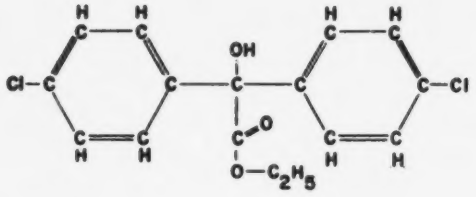
Methoxychlor is similar to DDT although it is usually less toxic to insects. Unlike DDT, which is stored in the fat and may appear as a residue in milk, methoxychlor is metabolized and excreted in the urine. It is therefore useful (as a dry dust) to control horn flies, lice and ticks on cattle; however, it must be applied more than five hours before milking time.

Methoxychlor – $C_{16}H_{15}Cl_3O_2$



Chlorobenzilate is the common name for a relatively new insecticide which offers considerable promise in controlling mites. Public health workers have used emulsions and suspensions of chlorobenzilate in controlling infestations of clover mites in and around buildings.

Chlorobenzilate – $C_{16}H_{14}O_3Cl_2$



Dilan is a mixture of prolan and bulan, derivatives of nitroparaffins. This liquid is miscible in organic solvents, but insoluble in water. Dilan has low toxicity to humans. The 2.5 percent emulsion is used for space spraying against DDT-resistant flies. Residual spraying with the 2.5 percent suspension at rates from 125 mg. to 200 mg. per square foot has controlled house flies for 6 to 13 weeks. Dilan and DDT may be mixed for fly control operations.

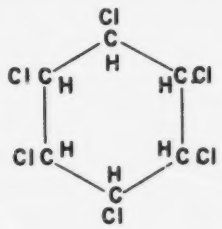
DMC is an abbreviation for the chemical name di (p-chlorophenyl) methylcarbinol. "Dimite" is a 25 percent emulsifiable concentrate of this insecticide. Although this chemical is employed in the control of mites, as its name would indicate, it has been shown to have value as a synergist for DDT space sprays. It appears that DMC is rapidly broken down by the flies permitting the DDT to penetrate to vital tissues and actually kill the flies.

Benzene Hexachloride Series

The two important insecticides in the benzene hexachloride series are benzene hexachloride (or BHC) and lindane.

Benzene Hexachloride or BHC – $C_6H_6Cl_6$

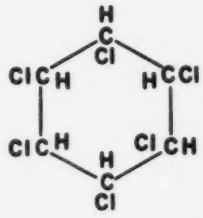
(chemical name – hexachlorocyclohexane)



Benzene hexachloride was first prepared by Michael Faraday in 1825. The discovery of the insecticidal activity of the compound seems to date from research of the French as early as 1940 and of the British independently about 1942. At the present time, structural forms or stereoisomers of BHC are known, designated alpha, beta, gamma, delta, epsilon, eta and theta (Frear, 1955). BHC should be purchased with careful reference to the content of the gamma isomer since this is the only isomer with great insecticidal value. Many commercial formulations of BHC contain about 12 percent gamma isomer.

BHC is a potent insecticide, toxic to a wide range of insect species of great importance in public health and agriculture. BHC is one of the three insecticides (with DDT and dieldrin) in general use as a residual spray in the world-wide Malaria Eradication Program sponsored by the World Health Organization. It is a good insecticide to use for the control of many species of flies and mosquitoes. The 3 percent agricultural dust is often dispersed by ground or aerial equipment to kill adult or larval forms. BHC is less toxic to fish than DDT. BHC is more volatile than DDT, a fact accounting for its short residual life of only two to six weeks. The fumes alone of this insecticide will kill some insects. The raw product has a disagreeable odor which imparts a musty flavor to some fruits and vegetables; hence, it should be used with care near agricultural crops. Technical grade BHC often contains 10 to 90 percent gamma isomer. The 99.5 percent gamma isomer is called lindane and is preferred for indoor use.

Lindane – $C_6H_6Cl_6$



Lindane (named for Von der Linden who published on the isomers of benzene hexachloride in 1912) is 99.5 percent pure gamma isomer of BHC. It has all the desirable qualities of the parent compound without either the chronic toxicity or the extremely objectionable odor. Although lindane in large doses is toxic to mammals, it is excreted rapidly by the kidneys. This action reduces the hazard from repeated exposure. Lindane is considerably more expensive than many other insecticides. Therefore, in such situations as outdoor space spraying of DDT-resistant house flies at city dumps, where odor is not a factor, 5 percent BHC is preferred to 2 percent lindane since it is cheaper and about equally effective. Lindane is much more toxic than DDT to most insects. Therefore, formulations are made only one-tenth as strong. For example, in areas where body lice are resistant to the standard 10 percent DDT dusts, 1 percent lindane powder has given excellent control. Lindane is a very useful material. It is toxic to a wide variety of insect pests, and acts as a contact poison, stomach poison, and fumigant. It has been recommended for the control of fleas, bed bugs, cockroaches, and ticks inside homes. It has a rather short residual action, however, and several insects, notably the house fly, are already resistant to this compound. One or two percent lindane sprays give rapid control (in a few minutes) of hornets, wasps, and yellow jackets when they are applied directly to the paper nests or to underground burrows, with particular attention to the entrances.

Use of lindane vaporizers may give control of flies or some other insects for a short period of time until resistance is developed. Several people exposed to concentrations of lindane and DDT from these vaporizers have developed urticaria, headache, and other symptoms (Council on Pharmacy and Chemistry, 1952). **The use of lindane vaporizers to control household insects is not recommended by any agency of the Federal Government.**

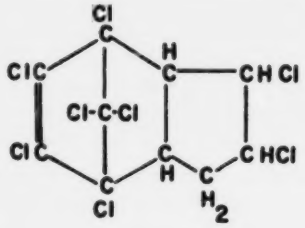
Chlordane Series

The insecticides in this series include chlordane, heptachlor, aldrin, dieldrin, isodrin, endrin, toxaphene, and most recently, Kepone (Kenaga, 1960). In many textbooks these highly chlorinated, cyclic hydrocarbons are classified as cyclodiene compounds because they have a characteristic "endomethylene bridged" structural formula. All of them, except toxaphene, are produced by the Diels-Alder diene reaction, for which the German chemists, Otto Diels and Kurt Alder, received the Nobel Prize in chemistry in 1950. Two of the insecticides in this series are named in their honor: dieldrin for Otto Diels and aldrin for Kurt Alder. However, the insecticides in this series are largely the work of Americans, Julius Hyman and his associates, beginning with the production of chlordane about 1945. As a group, these insecticides have been used increasingly in agriculture to control grasshoppers and cotton insects. Shepard (1960) reported that nearly 92 million pounds of these cyclodiene compounds were produced during the 1958-1959 crop year.

Public health workers and pest control operators use these compounds extensively for controlling household insects, particularly cockroaches, ants, and termites, and, to a lesser extent, for fly and

mosquito control. Some of these materials have killed fish, birds, mammals, and even human beings through accidents in handling the emulsifiable concentrates. For this reason, these insecticides should be applied carefully, following directions of the manufacturer to avoid toxic hazards.

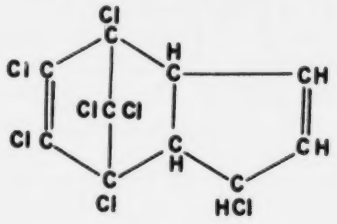
Chlordane – $C_{10}H_6Cl_8$



Chlordane is an amber, viscous liquid that can be mixed with kerosene, and other organic solvents. It is sold commercially as oil solutions, emulsifiable concentrates, technical chlordane, wettable powder, and chlordane dusts. Technical chlordane does not ordinarily crystallize, but forms a film on treated surfaces. The film is somewhat volatile, hence this insecticide usually has a shorter life than DDT but a longer residual action than BHC. Chlordane normally acts as a contact and stomach poison, but it also has a fumigant effect. Because of this fact, chlordane is not recommended for general residual applications indoors, especially in bedrooms. Indoor treatments are confined to localized applications in treating small areas for cockroaches. During the ten years 1946 to 1956, chlordane was probably the insecticide most widely used by the pest control industry, particularly for controlling cockroaches, ants, and termites. However, beginning about 1952, the German cockroach began developing resistance to chlordane; so alternate insecticides, primarily organophosphorus compounds, have gradually replaced it for German cockroach control. Chlordane is in general use for control of many species of arthropods, including chiggers, ants, and subterranean termites. A very finely ground chlordane dust is used extensively in southeastern United States for crab grass control.

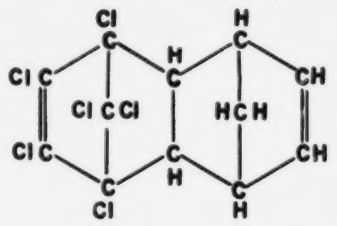
Heptachlor was developed as the most insecticidally active constituent of crude chlordane, being 4 to 5 times as toxic to many insects as chlordane. Heptachlor is also more toxic to human beings and other mammals and therefore is used more frequently outdoors than inside buildings. In controlling insects of public health importance, heptachlor is used especially as a very effective, relatively inexpensive, mosquito larvicide and for ant control.

Heptachlor – $C_{10}H_5Cl_7$



Aldrin (named for Kurt Alder, a German chemist who helped work out the Diels-Alder diene reaction for synthesizing these insecticides) is a broad-spectrum insecticide which is used to control some agricultural insects. It is used extensively in termite control because it is relatively inexpensive, is stable in alkali soils, and has a residual action for many years. Aldrin is readily absorbed through the skin and care must be taken to prevent skin contamination.

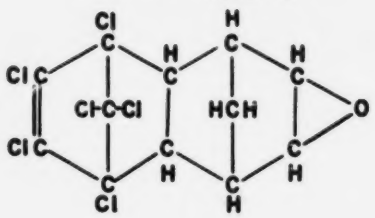
Aldrin – $C_{12}H_8Cl_6$



Dieldrin (named for Otto Diels) is considerably more toxic than DDT and is readily absorbed through the skin. Dieldrin is one of three residual insecticides (with DDT and BHC) used extensively as a residual spray to kill malarial mosquitoes in the world-wide Malaria Eradication Program. Because it is more toxic than DDT, dieldrin has been used at much lower concentrations as a residual spray, often as a 1.25 percent suspension. It has given effective control of DDT-resistant *Anopheles* in Arabia, Iran and Java. In South America, Africa, India, and Indonesia, spraymen applying residual sprays of dieldrin for malaria

control have become seriously ill, probably due to absorption of this insecticide through the skin. Hayes (1960) reported that "at least 90 persons showed full epileptoid convulsions and 11 have showed recurrence of illness several months after last exposure" to dieldrin. Dieldrin has been employed for outdoor house fly control when resistance to DDT has developed. However, in some areas DDT-resistant flies soon developed resistance also to dieldrin and other chlorinated hydrocarbon insecticides. Dieldrin has been used for chigger control as dusts or sprays applied at a rate of one pound of technical grade dieldrin per acre. Dieldrin has been approved for indoor application as spot treatments to control cockroaches, ants and earwigs. In South America it has been used as a residual spray to kill *Triatoma* bugs which transmit Chagas disease.

Dieldrin – $C_{12}H_8Cl_6O$



Isodrin and **endrin** are two other, very toxic, insecticides in the chlordane series. They are used to control agricultural insects but seldom those of public health importance. Residual sprays of endrin have been applied to vegetation in orchards to kill meadow mice and field rodents.

Toxaphene is a chlorinated camphene used chiefly in the control of agricultural pests. At the present time toxaphene is used alone, or in combination with lindane or malathion, as a livestock spray, dip, or dust to control horn flies, lice, ticks, and scabies mites.

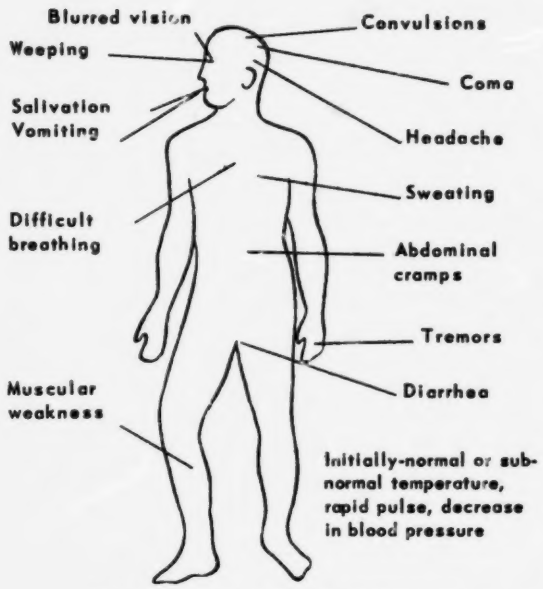
Kepone is a recently developed chlorinated polycyclic ketone compound that may have importance as a stomach poison in the control of the German and brown-banded cockroaches. Preliminary tests of Kepone peanut butter pellets containing 0.125 percent of actual toxicant provided cockroach-free conditions in a laboratory by the establishment of bait stations. The tiny pellets were sufficiently small to be carried back to their harborage by cockroaches. Field tests with the imported fire ant have proven successful, but more information is needed on the effect of Kepone on useful wildlife.

ORGANIC PHOSPHORUS INSECTICIDES

During World War II, the chemist, Gerhard Schrader, and his associates, worked in the Bayer laboratories in Germany. During their study of chemical warfare agents they synthesized over 300 compounds containing organically-bound phosphorus, including "nerve gases" like Tabun and highly toxic insecticides such as Schradan, TEPP, HETP, and parathion. Their research indicated that many of these compounds were highly toxic, both to warm-blooded mammals and cold-blooded arthropods. Since World War II, millions of pounds of parathion have been used in the control of agricultural insects, mites, flies, and mosquitoes. Continued research has led to the development of less toxic, broad-spectrum organophosphorus compounds such as Diazinon, malathion, and ronnel which are widely used in the control of arthropods of public health importance. **All of them work as inhibitors of the enzyme cholinesterase** (Metcalf, 1955).

The organic phosphorus insecticides are characterized by (1) similar structure (they may all be considered derivatives of phosphoric acid), and (2) similar mode of action. They are toxic to animals because of their ability to interfere with the normal mechanism of nerve impulse transmission. When a nerve impulse is transmitted, acetylcholine is liberated and acts directly upon effector cells to produce their characteristic response, such as the contraction of a muscle or the secretion of a gland. The enzyme cholinesterase is present in nerves and normally stops the response by hydrolyzing acetylcholine into the acetate ion and choline, essentially "clearing the deck" for the next nerve impulse. This reaction may occur in a tenth of a second or less. Part of the organophosphorus insecticides attach to cholinesterase in the nerve and prevent this enzyme from breaking down acetylcholine. If acetylcholine is allowed to accumulate, impulses continue to travel along the nerves and cause un-coordinated activity throughout the entire animal. The results are tremors, convulsions, muscle paralysis, and finally death from a variety of organ failures. Initial symptoms

of severe organophosphorus poisoning usually occur less than six hours after exposure to the insecticides. They include headache, weakness, and fatigue. Patients feel dizzy and nauseated. The pupils of the eye sometimes become contracted and the patient may have trouble focusing his eyes. Abdominal cramps set in, accompanied by vomiting and diarrhea, difficulty in breathing, profuse sweating, and excessive salivation, sometimes followed by convulsions, coma, and death. In cases of such poisoning, the intravenous injection of two milligrams of atropine, repeated at five to ten minute intervals, may save the patient's life (see Communicable Disease Center, 1956). More recently a new compound, PAM, has been tested by many investigators and shows great promise in the treatment of organophosphorus insecticide poisoning (Hayes, 1960). The range of toxicity of selected organic phosphorus insecticides generally used by public health workers is given in Table 2.4 below.



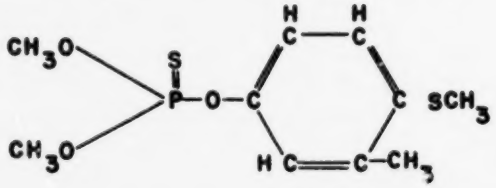
SYMPTOMS OF ACUTE POISONING
BY ORGANIC PHOSPHORUS INSECTICIDES

TABLE 2.4 TOXICITY OF SOME SELECTED ORGANIC PHOSPHORUS INSECTICIDES TO FEMALE LABORATORY RATS. Data largely from Gaines (1960).

	Insecticide	Acute Dermal LD_{50}	Acute Oral LD_{50}
Highly Toxic	TEPP	5	1.2
	Phosdrin	4.2	3.7
	Parathion	6.8	3.6
Moderately Toxic	DDVP	75	56
	Bayer 29493	330	245
	Diazinon	455	76
Slightly Toxic	Dipterex	2000	560
	Malathion	4444	1000
	Ronnel	–	2630

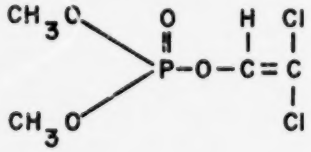
Bayer 29493 (Entex) is a relatively new organic phosphorus insecticide of moderate toxicity which has been registered for mosquito control as 5 percent granules, as wettable powder, and emulsion concentrate. It shows promise in mosquito, fly, and cockroach control, usually as 2 to 3 percent sprays.

Bayer 29493 – (Entex) – $C_{10}H_{15}O_3PS_2$



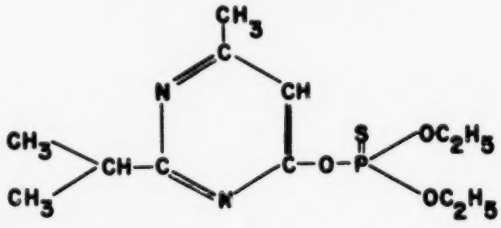
DDVP was synthesized and tested by workers of the Communicable Disease Center. It has a short residual life but is remarkable because of its highly volatile, toxic vapors. DDVP adds quick knock-down to many dry and liquid fly baits and its toxic vapor may aid greatly in "cleanout" applications on hard-to-reach infestations of cockroaches and brown dog ticks. It is being studied intensively by CDC workers as an insecticide for airplane disinsectization, with built-in dispenser systems. Sprays of 0.5 percent are recommended for many household insects including house flies, cockroaches, fleas, brown dog ticks, and exposed infestations of cigarette beetles and tobacco moths. Ultimately the greatest use of DDVP by public health workers may be as a residual fumigant in the world-wide Malaria Eradication Program (Communicable Disease Center, 1962).

DDVP – $C_4H_7O_4PCl_2$



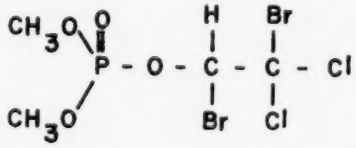
Diazinon is a moderately toxic insecticide which may be absorbed through the skin and is known to kill poultry when introduced into feed. One percent sprays have been used for fly control in food plants, and residual bait sprays containing 2.5 percent Diazinon and 6.25 percent sugar have given effective fly control for a month or more. Fly cords impregnated with Diazinon alone, or a mixture of Diazinon-parathion, are used extensively in dairy barns, loading platforms, and similar situations. Diazinon is the insecticide of choice for controlling many household insects, particularly German cockroaches that are resistant to the chlorinated hydrocarbons and malathion. One percent sprays are recommended for the first application, with 0.5 percent sprays or 5 percent dusts for routine follow-up. Diazinon has a short residual life, and may give spotty control, on impervious surfaces such as glass, tile, or metal. Diazinon resistance in flies and roaches has been reported.

Diazinon – $C_{12}H_{21}O_3N_2PS$



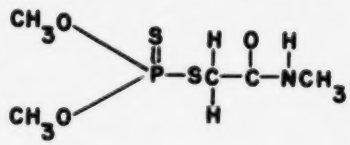
Dibrom is a recently developed organic phosphorus insecticide that is closely related to DDVP. Dibrom is a contact and stomach poison with a limited amount of vapor toxicity. The technical grade insecticide is liquid at room temperature. Dibrom may be purchased as a 64.5 percent emulsifiable concentrate containing 8 pounds of Dibrom per gallon or as a 4 percent dust. In aerial treatments against Florida salt-marsh mosquito adults, oil solutions at application rates of 0.05 to 0.1 pounds Dibrom per acre produced excellent kills. Dibrom may be used in a liquid bait for flies in dairy barns or in space sprays for fly control.

Dibrom – $C_4H_7O_4Br_2Cl_2$



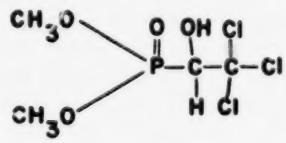
Dimethoate is a promising new organic phosphorus insecticide for outdoor fly control. Unpublished research by CDC indicated that dimethoate controlled flies for 6-10 weeks in dairy barns in 1960. It was one of the best residual insecticides for controlling flies that are resistant to chlorinated hydrocarbons and some organophosphorus compounds. Dimethoate should be used with caution indoors since reputable workers have reported some staining and objectionable odor in preliminary testing.

Dimethoate – $C_5H_{12}NO_3PS_2$



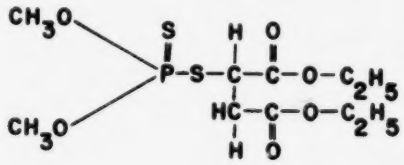
Dipterex. This organic phosphorus insecticide is water-soluble and therefore is often used where the odor of insecticides or solvents is a problem, as in hospitals, or eating establishments. Dipterex is a rapidly-acting stomach poison which is used to control flies as a 1 percent dry sugar bait or as a 0.1 percent liquid bait in dairy barns, poultry houses, stables, kennels, picnic areas, and garbage areas. It may also be effective against cockroaches by spot applications of 1 to 2 percent solutions or emulsions, or as a dry sugar bait.

Dipterex – $C_4H_8O_4PCl_3$



Malathion is one of the safest of the insecticides, being less toxic than DDT. It is a broad-spectrum compound, effective against a wide range of mite and insect pests, including house flies, cockroaches and mosquitoes which are resistant to DDT and other chlorinated hydrocarbon insecticides. Certain commercial formulations have a disagreeable odor. Premium grade preparations, or deodorized formulations with a masking odor, are available commercially for indoor use. Up to 5 percent sprays are used for spot treatments in buildings for cockroach control, particularly for German cockroaches resistant to the chlorinated hydrocarbons. Up to 4 percent sprays are used for controlling many crawling arthropods and fleas. Five percent malathion with 12.5 percent sugar is recommended as a residual spray for fly control. Mist and fog formulations with 6.5 percent fuel oil solutions of malathion have given effective kill of DDT-resistant flies and mosquitoes. In the United States and in Latin America 5 percent suspensions of malathion have given good residual control of *Anopheles* mosquitoes resistant to dieldrin and DDT. Three to five percent malathion dusts, or 0.5 percent sprays, give effective control of DDT-resistant cat or dog fleas for one or two weeks (or longer) in summer and a month or more in winter. One percent sprays will kill DDT-resistant bed bugs and clover and bird mites. One percent malathion dust has given effective control of human lice resistant to DDT or lindane. Malathion resistance has been reported in some species of flies and mosquitoes.

Malathion – $C_{10}H_{19}O_6PS_2$

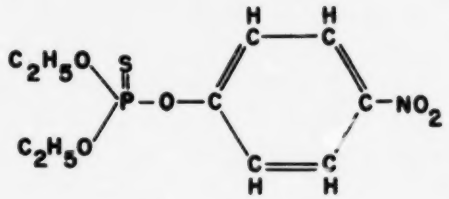


Parathion is closely related to the highly toxic chemicals tetraethyl pyrophosphate (TEPP) and hexaethyl tetraphosphate (HETP). These compounds are dangerously toxic to animals through inhalation, through skin absorption, or by mouth.

Data of Shepard (1960) indicate several million pounds of parathion have been used annually in recent years, chiefly for the control of agricultural insects. A number of deaths due to parathion have been reported by Hayes (1960) in many parts of the world. In 1960 CDC workers reported that the lives of two agricultural workers with acute poisoning due to parathion were saved by the prompt administration of PAM. Parathion has two chief uses by public health workers, as fly cords and in mosquito control. Parathion-impregnated cords are approved for fly control in dairy barns and similar situations, some 25 million feet having been sold in 1960. Parathion has been used at 0.05 to 0.1 lb. of technical material per acre to control DDT-resistant mosquitoes (*Culex tarsalis, Aedes nigromaculis,*

A. sollicitans, or *A. taeniorhynchus*) usually as emulsions, solutions, or granular insecticides.

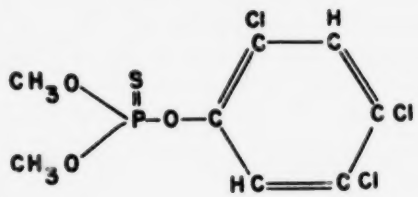
Parathion – $C_{10}H_{14}NO_5PS$



Ronnel is the common name for a number of products with such trade names as Korlan, Dow ET-14, or Dow ET-57, and Trolene, which have a low mammalian toxicity and give effective control of a wide variety of arthropods. Ronnel may be used for fly control in dairy barns and food-processing plants; for cockroach, mite, tick, spider, flea and bed bug control in buildings and yards, usually as a 1 to 2 percent spray. Ronnel is reported to have less of an objectionable odor than malathion, particularly if applied in oil, and it does not stain whitewashed surfaces. Sprays have been used to control ectoparasites on cattle. It is one of the more promising systemic insecticides for cattle grubs, and ectoparasites of dogs such as lice, ticks and fleas.

There are many other organic phosphorus compounds which are used in agriculture or are being tested for the control of arthropods of public health importance. Kenaga (1960) listed 80 organic phosphorus compounds available for control or experimental use on June 1960 Shepard (1960) listed 26 such compounds which were in "commercial or semi-commercial production" for insecticidal and miticidal uses in the United States in early 1960.

Ronnel – $C_8H_8O_3Cl_3PS$



ORGANIC THIOCYANATES

Many of the aerosols for household insects and cattle sprays and the oil-base contact insecticides for general application in household, dairy, mill, and warehouse disinfestation contain one or more of the organic thiocyanates. Currently these compounds are also being used in airplane applications, and fog and mist machines, for pest mosquito control – either in fuel oil, or in combination with fuel oil solutions containing DDT or malathion. The organic thiocyanates are efficient contact insecticides which produce rapid knockdown of insects, have a low toxicity to warm-blooded animals, and rarely cause damage to vegetation. These insecticides are also reported to be heat stable, an important factor in choosing insecticides for use in thermal fog generators. Metcalf (1955) has written, "In general, the thiocyanate group – SCN – is associated with unpleasant odors which render the compounds somewhat unsuitable for household sprays. Thiocyanoacetates, incorporating the group $OCOCH_2SCN$, are generally less unpleasant, have high knockdown activity, and are highly toxic. However, these substances are more irritant than the corresponding thiocyanates." Metcalf (1955, p. 108) also cited work of Coon on the American cockroach, indicating that lethane might act as a respiratory poison, somewhat like hydrogen cyanide, causing a sharp drop in heart beat followed by a rise and leveling off, and a greatly reduced blood circulation. Some of the thiocyanate group used by public health workers include:

Loro (lauryl thiocyanate) has the molecular formula $C_{12}H_{25}SCN$. It was used during World War II in louse control and apparently was not as toxic as some other members of the group.

Lethane 384, $C_4H_9OCH_2CH_2OCH_2CH_2SCN$ and Lethane 384 Special, $C_{11}H_{23}COOCH_2CH_2SCN$.

Lethane is the trade name for a group of thiocyanates used in the control of household and dairy insects. Lethane 384 Special and Lethane 384 are added to petroleum house sprays as the sole toxic agents or in combination with DDT and other materials. The lethanes are of value because of the rapid knockdown of flies or mosquitoes produced.

In Florida, fogging with a fuel oil solution of malathion and lethane has given good control of adult mosquitoes.

During World War II, Lethane 384 was used to kill human lice, but was found to be irritating to the skin of Caucasians. Therefore, Loro (lauryl thiocyanate) was substituted. (Brown, 1951.)

Thanite, $C_{10}H_{17}OOCCH_2SCN$ – is one of the thiocyanates used as a knockdown agent for flies. It is employed chiefly for cattle sprays and for general applications in the home, dairy, mill, or warehouse. Thanite exhibits very low toxicity to mammals.

ORGANIC NITROGEN GROUP

A group of dinitro derivatives of phenol and cresol came into use before the Second World War as dormant sprays in apple orchards. Others have been used in louse powders, as moth-proofing agents, screw-worm dips, and mosquito larvicides. In general, these compounds are not commonly used by public health workers. Some of the dinitrophenols are spoken of as "DN" compounds, Kenaga (1960) listed 6 of these as nitrophenyl compounds. Good discussions are included in the books by Shepard (1951) and Brown (1951). Brief remarks are here included of those compounds listed on the chart on the inside cover.

Dinitrophenol – insecticide and acaricide

DNOC – a powerful insecticide and ovicide

DNOCHP – dinitrocyclohexylphenol, acaricide

DNOSBP – insecticide

Diphenylamine – the chief constituent of "Smear 62" screw-worm dip

Azobenzene – kills mosquito larvae and red spiders

Karathane – insecticide, acaricide, and mite ovicide

Prolan and Bulan – constituents of Dilan used to kill DDT-resistant flies

Dinitronaphthol – a mothproofing agent

Dinitroanisole – a constituent of the MYL louse powder, kills louse eggs

Dinitrocresylate – acaricide

The action of the nitrophenols and nitrocresols has been studied in insects. These compounds are reported to increase both carbohydrate and fat metabolism and the rate of respiration. Insects exposed to DNOP and DNOC respond with rapid motions, contortions, and quick knockdown, often followed by paralysis and death in 30 to 60 minutes. DNOC penetrates the insect tissues rapidly and precipitates protein in the cuticle and hypodermal cells (Brown, 1951).

ORGANIC SULFUR GROUP

The organic sulfur group includes the relatively new carbamate compounds (Sevin, Isolan, Dimetilan, and Pyrolan) and a number of older compounds discussed below. If insects of public health importance continue to develop resistance to the chlorinated hydrocarbon and organic phosphorus insecticides, Sevin, Isolan, Dimetilan, and Pyrolan may play a more important role in practical control programs. These new insecticides are esters of carbamic acid, and are related to the fungicides thiram, ferbam, ziram, nabam, zineb and certain new herbicides.

Gaines (1960) reported that rats poisoned with Sevin and Isolan exhibited toxic symptoms similar to those resulting from exposure to organophosphorus insecticides, probably as a result of lowered cholinesterase levels, including muscular twitching, excessive salivation and lacrimation, tremor, diarrhea, and involuntary urination.

Sevin. This is the first of the carbamate insecticides which shows good control of arthropods of public health importance. It has been used against resistant brown dog ticks as an 0.5 percent spray indoors or as a five percent dust for general tick and flea control outdoors. It has been used as a dust for control of fleas on pets and of the face fly (*Musca autumnalis*) on dairy cattle.

Isolan. This insecticide has a rapid pyrethrum-like action on flies and is also effective against bed bugs. Its residual action is of short duration according to Metcalf (1955). Gaines (1960) reported that it was considerably more toxic to rats by the dermal route than by the oral route.

Dimetilan. Fly bands impregnated with Dimetilan produced effective fly control for several months in Savannah, Georgia in 1959.

Lauseto neu was developed by the Germans during World War II as a powerful insecticide to

control human lice, especially as an ovicide. If body and head lice continue developing resistance to synthetic organic insecticides, **lauseto neu** may come back into general use again.

Phenothiazine was developed as a mosquito larvicide and later was widely used in controlling agricultural insects. Several million pounds a year are used to destroy internal parasites of livestock. It is also used to control hornfly maggots which develop in fresh cow manure.

The other organo-sulfates listed on the chart on the inside front cover, Aramite, Genitol, Ovex, and Sulfenone, are primarily acaricides used to control agricultural pests. They have limited use by public health workers in controlling clover mites and blood-sucking mites of birds or mammals, such as infestations of pigeon or chicken mites swarming on buildings.

NATURAL ORGANIC INSECTICIDES

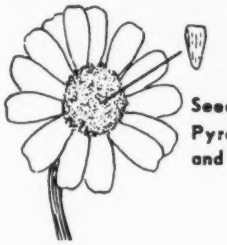
INSECTICIDES OF PLANT ORIGIN

Plant materials furnish some of the most widely known and safest insecticides. The flowers, leaves, or roots may be ground into an insecticidal dust, or the toxic ingredients may be extracted to prepare a liquid concentrate. Pyrethrum, rotenone, derris, hellebore, nicotine, quassia, camphor, and turpentine are some of the more important plant products used for killing insects. For more complete accounts the books by Brown (1951), Shepard (1951) or Frear (1955) should be consulted.

Pyrethrum. A powder made from the ground-up heads of pyrethrum flowers has been used for hundreds of years in Iran, and for over a century in present-day Yugoslavia, hence the names Persian or Dalmatian insect powder. Before World War I, pyrethrum was grown in California and Dalmatia (coastal Yugoslavia). From 1920 to 1940 much of the world supply came from Japan and Kenya. Shepard (1960) reported that in 1958 and 1959 most of the pyrethrum used in the United States came from British East Africa, Belgian Congo, Ecuador, and Jugoslavia where it was grown at elevations of 6500 to 9500 feet.

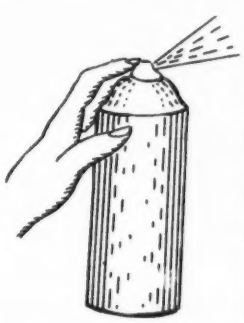
Pyrethrum is the important insecticide in many aerosol bombs and insect sprays because it produces a quick knock-down of cold-blooded arthropods but has little toxicity to warm-blooded animals. For these reasons pyrethrum sprays or "bug bombs" are used in homes, restaurants, airplanes, and dairy barns. Pyrethrum is one of the few insecticides which can be safely used in milk rooms and pasteurization plants.

The insecticidal principle is found in the flower heads of certain daisies, principally 3 species of the genus *Chrysanthemum*, of which *Chrysanthemum (Pyrethrum) cinerariaefolium* is the most important. The dried flower heads contain between 0.5 and 3.0 percent of an oily liquid composed of four complex esters called pyrethrins, I and II and cinerins I and II, hence the term pyrethroids. The flower heads are ground to a fine



Seed or achene contains 90% of Pyrethrin I, Pyrethrin II, Cinerin I and Cinerin II

powder for efficient extraction. The standard household spray formerly was prepared by extraction at a rate of 1 pound of ground flowers per gallon of refined kerosene, giving a concentration of about 0.1 percent of pyrethrins. The concentrates are prepared from the ground flowers by extracting with volatile solvents such as petroleum ether, ethylene dichloride, or methyl alcohol. After evaporation, the pyrethroids remain as complex oleoresin concentrates. Two chief commercial forms are available: the **20:1 concentrate containing about 2.5 percent pyrethrins** which is diluted twenty times by volume (or 1 part to 19 parts) with deodorized kerosene to form insect sprays containing 0.1 percent pyrethrins for flies and mosquitoes, or 1 part to 9 parts to form the standard New Jersey larvicide concentrate used to control mosquito larvae in fish or lily ponds where other insecticides might harm valuable fish or plants. For aerosol use it is necessary to use a more highly refined and concentrated form. **The standard**



pyrethrum extract for aerosol formulations contains 20 percent pyrethrins, easily confused with the 20:1 concentrate that contains only about 1/8 as much pyrethrins. Because of the high cost of pyrethrum, it is now common practice to add a synergist, such as piperonyl butoxide, making it possible to use a low concentration and obtain an effective kill. One standard formula for aerosol bombs, developed by the U. S. Department of Agriculture (1955), contains 0.4 percent pyrethrins to produce a quick knock-down of insects, 1 percent piperonyl butoxide as synergist, 2 percent DDT to produce final kill of the insects, and about 96 percent aerosol propellent, largely Freon-11 and Freon-12. There are, of course, many other combinations with other synergists.

Allethrin. In 1949 workers of the U. S. Department of Agriculture synthesized an insecticide similar to the allyl homologue of cinerin I, an ingredient of pyrethrum, hence the common name allethrin. This is produced in much higher concentrations than pyrethrum extracts and must be diluted according to directions before use. The material is mixed with synergists such as piperonyl butoxide and MGK 264. Large scale production of allethrin may bring about lower costs and increased use for space spraying. Flies and mosquitoes have not developed resistance to pyrethrum and allethrin in the field. Allethrin appears to be one of the safest insecticides known.

Rotenone. The fish poisons, rotenone, derris, cube, and their relatives are among the safest, generally-used insecticides. Natives in tropical countries have used the roots of certain legumes which were crushed and thrown in water to paralyze fish. The roots of these plants are extracted to produce rotenone, a white, crystalline solid, and various spray mixtures. Rotenone acts as both a stomach and contact poison, slowing the heart beat and causing respiratory paralysis. It is effective against many arthropods of public health and agricultural importance but has low mammalian toxicity, hence it may be used on garden crops to the time of harvesting and on dogs, cats, and domestic animals to control fleas, lice, ticks, and flies. It is applied to the backs of cattle to control the cattle grubs (*Hypoderma*).

Ryania. Ryania is an insecticide extracted from the stems and roots of several species of **Ryania** found in South America. This chemical acts as both a contact and a stomach poison, death of insects following a prolonged paralysis. Ryania has a very low toxicity to warm-blooded animals hence it is often used on vegetables to protect them from insect attack. Present formulations do not appear to offer much promise for the control of chlordane-resistant cockroaches.

Sabadilla. Sabadilla is an insecticide obtained from seeds of the sabadilla plant, a member of the lily family found in Mexico and South America. The seed may contain 2 to 2.5 percent of the active principle. This material is used against cattle lice and has been tested experimentally against house flies and many other insects. Sabadilla exhibits low toxicity to warm-blooded animals.

Nicotine. Nicotine was used as early as 1690 when a tobacco wash was applied in France to control the pear lace bug. Nicotine sulfate is prepared from tobacco wastes which contain about 0.5 percent nicotine, and low grade leaf tobacco with as much as 3 percent nicotine. Nicotine sulfate is marketed as a 40 percent nicotine extract that must be diluted before use, commonly in 1:600 or 1:800 dilutions. Fumes from sprays or dusts penetrate the respiratory tracts of insects causing paralysis of the nervous system. Nicotine may cause human deaths in from 5 to 30 minutes and the smallest single fatal dose for man appears to be about 60 mg. However, nicotine sulfate has a good safety record due in part to its disagreeable odor.

PETROLEUM OILS

Crude petroleum oils are complex mixtures of gaseous, liquid, and solid hydrocarbons which may be separated by fractional distillation into at least the following six general classes:

1. Naphtha, gasoline, petroleum ethers. Boiling range 70 to 150° C.
2. Kerosene. Boiling range, 150° to 300° C.
3. Fuel oils. Boiling range, 250° to 350° C.
4. Lubricating oils, petrolatum 300° C. and upward
5. Paraffin wax, separated from (4) by chilling
6. Asphalt, tar, pitch, coke. Remaining as residues.

FUEL OIL AND KEROSENE

Although petroleum oil distillates such as kerosene and fuel oil will kill most insects if brought into intimate contact with them, public health workers use oils chiefly as solvents for insecticides. Table 2.5 lists physical properties of some of the organic solvents.

Several chemical and physical properties of oils are important in insect control. **Viscosity,** or "body," of the liquid determines the rate at which the insecticide will flow through an orifice at a certain temperature and pressure. **Density** refers to the weight of the oil per unit of volume. Kerosenes commonly employed as insecticide base oils have a specific gravity of 0.78-0.80. The **flash point** is the minimum temperature at which a heated oil will give off inflammable vapor in sufficient quantity to produce a combustible mixture. This figure is important in determining the fire hazard created by oil solutions. Other factors, such as surface tension, odor intensity, and sulfonation are important in preparing specifications for spray oils. **Sulfonation** indicates the degree of safety for applications to plant and animal life as it represents the degree of refinement of the oil.

Public health workers have used fuel oil No. 2 and kerosene as mosquito larvicides for many years. Research indicates that there is a toxic fraction with a low boiling point and high volatility which penetrates the tracheae of larvae and pupae and produces an anaesthetic effect, and a lasting fraction which acts more slowly and generally does not have any direct toxic action but suffocates by mechanical interference with breathing. Early mosquito control workers used 15 to 50 gallons of fuel oil or kerosene per acre to obtain satisfactory control. Today, the addition of 2 to 5 percent of a spreading agent has made it possible to obtain control with 3 to 10 gallons per acre. Fuel oil No. 2 is the commonest solvent of the new synthetic insecticides such as DDT used for larviciding, fogging or misting, particularly with ground equipment. In making emulsifiable concentrates and formulations for airplane applications it is often desirable to use a higher concentration of these insecticides than can be dissolved in fuel oil No. 2, so some of the other solvents listed in Table 2.5 such as xylene are used.

THE SULFUR AND COPPER GROUPS

Sulfur. The element sulfur was known as an insecticide as early as 1000 B.C. Sulfur dust is employed by the camper for the control of chigger mites and by the home gardener for the control of mites and red spiders although more effective materials are available. Lime-sulfur is an excellent fungicide, as well as an acaricide for controlling ear mites on animals.

Sulfur dioxide has been used for centuries as a home fumigant. This gas is formed by burning sulfur candles. This material tarnishes metals, weakens or bleaches textiles, and injures some foods, and should no longer be used in bed bug control. Sulfur dioxide is not extremely hazardous to humans as very small concentrations cause one to cough, giving ample warning before a dangerous exposure occurs.

Copper sulfate is known as blue vitriol, or bluestone. This material is employed chiefly as a fungicide in agriculture but may be applied to lakes and ponds to reduce the occurrence of algae and other vegetation. There is considerable danger of killing all fish when using copper sulfate as a weed killer in ponds.

THE MERCURY GROUP

Mercuric chloride, $HgCl_2$, is a white crystalline, water soluble substance often called corrosive sublimate or bichloride of mercury. This material is employed in controlling fungi and is used in the home for making ant tape, strips of cotton material soaked in a solution of mercuric chloride. These tapes are fastened around the legs of furniture to repel ants. Needless to say, this material is hazardous for use in the home.

Mercurial ointments containing about 10 percent mercury (blue ointment) were a widely-used, old-fashioned remedy for human lice. These mercurial ointments are irritating and may be dangerous when applied to large areas of the body. The new synthetic insecticides such as DDT, lindane, and malathion are more effective and less toxic compounds for controlling lice.

TABLE 2.5 PHYSICAL PROPERTIES OF SOME COMMON SOLVENTS*

Solvent	Density	Flash Point	Solubility of DDT
	(Lb./Gal.)	(°F)	(Lb./Gal. of Solvent)
ORGANIC COMPOUNDS			
Acetone	6.6	14	4.8
Benzene	7.3	less than 20	6.5
Cyclohexanone	7.9	122	9.7
ortho-Dichlorobenzene	10.8	167	4.9
Xylene (10 degree)	7.2	80 - 85	4.4
Petroleum oils:			
Fuel oil No. 1	6.9	less than 130	0.7 - 0.9
Fuel oil No. 2	7.1	130	0.6 - 0.8
Kerosene, crude	6.8	150	0.7 - 0.8
Kerosene, odorless	6.8	125	0.3
Stoddard solvent		more than 100	0.8
OTHER HYDROCARBON SOLVENTS			
Bronoco Hi Sol No. 100	8.3	more than 250	2.9
S/V Sovacide 544-B	8.3	275	3.8
544-C	7.9	245	3.2
544-F	7.8	250	2.3
Umex. 4060	7.8	210	2.3
Velsicol AR-50	8.1	230	4.6
AR-60	8.3	220	4.6
NR-70	8.7	300	4.3
NR-70	8.2	200	4.4
Water (for comparison)	8.34	None	Trace

* Adapted from Table 1, Circular No. 977, U.S.D.A.

STOMACH POISONS

The great majority of arthropods of public health importance (adult flies, mosquitoes, fleas, lice, true bugs, ticks and mites) have mouth-parts adapted for sucking blood. The control of these arthropods therefore is accomplished largely by contact insecticides. These compounds are also used to control cockroaches, mosquito and fly larvae which have chewing mouth-parts. However, as these last insects have become resistant to contact insecticides, stomach poisons such as sodium fluoride and Paris green are coming back into use. Certain other insecticides such as rotenone, dipterex and a number of the organic phosphorus compounds used in residual bait sprays also act as stomach poisons, but have already been discussed under the contact poisons.

THE ARSENIC GROUP

White Arsenic and Paris Green. White arsenic is the common name for arsenic trioxide, a material obtained from mineral ores and used in the preparation of arsenical compounds. It is the base for Paris green, lead arsenate, calcium arsenate, and sodium arsenite. The arsenicals are general protoplasmic poisons. In insects they are absorbed primarily in the mid-intestine where they cause break down of the cells and abrasion of the intestinal lining. Paris green, copper-aceto-arsenite, was first used as a pigment in paints. It was first employed as a poison dust against the Colorado potato beetle in 1867. From the 1920's to about 1945, when the new synthetic insecticides came into wide usage, Paris green dust diluted with hydrated lime, road dust, or other inert carriers was widely used to control anopheline mosquito larvae. More recently, Rogers and Rathburn (1960) have carried out research indicating that Paris green-vermiculite granules gave excellent control of both anopheline and DDT-resistant culicine larvae in Southeastern United States. Sodium arsenite solution is a well-known weed killer, but it also frequently encountered by public health workers in ant baits.

THE FLUORINE GROUP

Fluorine Compounds. The element of fluorine occurs commonly in nature as fluorspar and cryolite. **Cryolite** is an unusually safe insecticide used in controlling chewing insect pests of orchard and vegetable crops. **Sodium fluoride** was used as a dust for cockroach control before the development of DDT and chlordane. As German cockroaches are becoming resistant to chlordane and other synthetic insecticides, sodium fluoride is coming back into use again – usually as a mixture of this insecticide, pyrethrum, and an inert carrier. Sodium fluoride is toxic to humans and may cause death when taken internally in quantity. Therefore, this white powder is tinted blue or green for identification purposes. It should never be stored with food. **Sodium fluosilicate** is used in wet-mash baits for many insects and also is a fairly effective moth-proofing agent for woolens. **Sodium monofluoroacetate** (commonly known as **1080**) is an extremely toxic compound used in rodent, bird, and predator control. 1080 has caused human deaths and should be used only by qualified pest control operators or public health workers, with strict precautions.

OTHER GROUPS

Borax. Borax (sodium tetraborate) has been used for controlling cockroaches for many years, although it is largely replaced by sodium fluoride, chlordane, or other organic insecticides. Roach tablets are useful for controlling cockroaches in bookcases. Public health workers may find borax effective in treating manure and other feces for house fly control. Not over 10 ounces of this powder may be applied to eight bushels of manure if manure is intended for fertilizer, as an excess of borax is harmful to the soil.

Lead Compounds. Lead arsenate is a common insecticidal dust or spray for chewing insects affecting garden and truck crops. This material is doubly toxic to humans, as both lead and arsenic are cumulative poisons, which are stored in body tissues, causing chronic poisoning.

Phosphorus Compounds. Yellow phosphorus is a solid which changes to an ineffective red form upon exposure to light or high temperature. Phosphorus paste is sometimes used for controlling American and oriental (but not German) cockroaches and rodents. This highly toxic material should be used with proper regard for children and pets. Yellow phosphorus is flammable at ordinary temperatures and may start fires.

Tartar Emetic. Tartar emetic is an antimony compound employed in ant baits and various agri-

cultural sprays. This chemical is toxic to humans despite its emetic effect. Tartar emetic is a water-soluble white powder.

Thallium Sulfate. Thallium sulfate is a crystalline, water-soluble compound used in ant and rat poisons. This very deadly cumulative poison is readily absorbed through the skin and should never be mixed with bare hands. It must be placed with extreme care. Fortunately, the ready-made ant baits contain a very low percentage of thallium.

FUMIGANTS

Fumigants kill insects by penetrating the body wall and respiratory tract in gaseous form. They are dispersed as true gases so that they reach the pest in molecular form. Molecules of gas can penetrate cracks and crevices or penetrate tightly packed materials. At the end of the fumigation period, doors, windows, or vents must be opened and the gas diffuses away until it is finally dissipated. By contrast, aerosols, commonly referred to as fogs or smokes, are discharged as very fine particles of liquid or solid which remain suspended in the air sufficiently long enough to distribute themselves throughout the area and act upon exposed insects. Aerosols are unable to penetrate into materials because their particles are deposited at the outer surfaces.

Monro (1960) and Brown (1951) have given an excellent discussion of fumigants of use to public health workers and pest control operators. They pointed out that the number of fumigants in practical use is limited by the following factors:

1. Inflammability – many must be mixed with non-flammable materials
2. Toxic hazards to operators
3. High reactivity – including the problem of residues or residual odors in foods
4. Tendency to corrode metals
5. Lack of chemical stability, and
6. Cost.

Some inflammable materials such as carbon disulphide must be mixed with non-flammable compounds such as carbon dioxide or carbon tetrachloride to produce an effective fumigant mixture which does not have a fire or explosion hazard. All the modern fumigants which give effective pest control are also toxic to man. Therefore, all fumigators should receive thorough training, be provided with proper equipment, and be informed of all hazards associated with the materials they are using. Fumigants are purchased in solid, liquid or gaseous form.

SOLIDS

Naphthalene ($C_{10}H_8$). This is obtained from the distillation of coal tar. The product is marketed as moth balls or flakes for controlling clothes moths and carpet beetles. Naphthalene has value as a repellent against squirrels and rats. It has been replaced to a large extent by PDB for most purposes.

Paradichlorobenzene ($C_6H_4Cl_2$). PDB is one of the earliest chlorinated hydrocarbon insecticides. It is used chiefly for protecting woolens and furs and insect collections from insect attack, and as a deodorant. It may be used to control fly breeding in garbage cans by the application of two ounces per can every one to two weeks.

LIQUIDS AND GASES

The two gases most commonly used by public health workers are hydrogen cyanide and methyl bromide. Kenaga (1960) listed 33 fumigants available in June 1960. Table 2.6 lists some of the more important fumigants used by public health workers and pest control operators.

Hydrogen Cyanide (hydrocyanic acid or HCN). This gas is widely used to control insects and rodents. It has no value in fumigating homes to destroy the organisms of disease, despite common belief. Cyanide should be used only by well-trained, bonded operators as it is extremely hazardous. Cyanide is sold in several forms. Cyanide eggs (sodium cyanide) react with a weak solution of sulfuric acid to produce HCN gas by the old pot method of fumigation. Liquid HCN is available in cylinders for treating chambers or buildings. HCN-impregnated discs (discoids) and granules are in common use. Calcium cyanide (Cyanogas A dust) is a powder that gives off HCN on exposure to atmospheric moisture. It is blown into rat burrows to control both rodents and their ectoparasites.

TABLE 2.6 SELECTED DATA ON THE MORE IMPORTANT FUMIGANTS
(Adopted from Monro, 1960)

Fumigant	Boiling point Degrees F.	Inflammability limits percent in air by volume	Solubility in water	Significance of residues in foodstuffs	Remarks
Acrylonitrile	171	3 - 17	Slightly	Fixed residues apparently of no significance. Not widely used at present for food fumigation.	Must be mixed with non-inflammable substance to avoid fire hazard.
Carbon disulphide	115	1.25 - 44	Very slightly	Vapour or fixed residues apparently negligible after normal aeration.	Must be mixed with non-inflammable substance to avoid fire or explosion hazard.
Carbon tetrachloride	170	Non-inflammable	Very slightly	Fixed residues apparently of no significance. Desorption of vapours may be slow.	More often used in mixtures to reduce fire hazard of other more toxic but inflammable fumigants.
Chloropicrin	234	Non-inflammable	Very slightly	Fixed residues apparently of no significance. Vapours will diffuse very slowly from material after fumigation.	Strong tear gas, often used in small amounts with other fumigants to serve as warning agent.
Ethylene dibromide	269	Non-inflammable	Very slightly	Fixed residues usually low. Desorption of vapours sometimes very slow from certain products.	If used alone in space fumigation must be volatilized by heat.
Ethylene dichloride	183	6.2 - 15.9	Very slightly	Fixed residues not significant. Desorption of vapours may be slow.	Must be mixed with non-inflammable substance to avoid fire hazard.
Ethylene oxide	51	3 - 80	Infinitely soluble	Reacts readily with certain components of food. Under normal fumigating conditions residues of no nutritional significance.	Must be mixed with non-inflammable substance to avoid explosion hazard.
Hydrogen cyanide (HCN)	79	5.6 - 12.8	Infinitely soluble	Fixed residues with most materials negligible. Vapours may be slow in desorbing.	Avoid presence of flames or sparks from electrical appliances during fumigation.
Methyl bromide	38.5	Non-inflammable	Very slightly	Fixed residue of bromide detectable by chemical analysis. May be off-odours in some materials. Vapours usually dissipate quickly after treatment.	Odourless except in very high concentrations. Small amounts of warning gas (chloropicrin) often added.
Phosphine	minus 125	1.79 lowest point	Very soluble	Fixed residues apparently of no significance. May be some residual odour in certain products.	In practice fire hazard avoided by generating fumigant from small tablets which also give off carbon dioxide and ammonia.
Sulfuryl fluoride	minus 67	Non-inflammable	Practically insoluble	No information available as yet on residues. Not at present recommended for food fumigation.	Developed as possible substitute for methyl bromide in fumigation of houses to control termites.
Sulphur dioxide	14	Non-inflammable	Very soluble	Used for bleaching some fruits. Residual taint may be undesirable in some products.	Strongly irritating and therefore safe in household fumigation. Not very toxic to insects.

Methyl Bromide (CH_3Br). This heavy gas has great penetrating power for fumigation of vermin-infested clothing and stored products. It may be purchased in pound cans or large cylinders from which the gas is released through tubing into the area to be treated. Methyl bromide is non-inflammable. It does not have a warning odor, so two percent chloropicrin is often added to overcome this disadvantage.

OTHER FUMIGANTS

Other fumigants which are used particularly in fumigation of stored foods are listed below.

Acrylonitrile ($CH_2-CH-CN$). This fumigant is inflammable and is usually used as mixtures containing 1 part acrylonitrile and 2 parts carbon tetrachloride. It is useful as a local or "spot" fumigant, particularly for machinery in flour mills and bakeries.

Carbon Disulphide (CS_2). This is a pale yellowish liquid used as a soil fumigant, particularly for ant nests, and for grain fumigation in the tropics. It is highly inflammable and explosive and has largely been replaced by other fumigants. Carbon disulphide must be handled with adequate follow-up ventilation to avoid toxic symptoms in man.

Carbon Tetrachloride (CCl_4). This compound is commonly used in household solvents and fire extinguishers. It is not very toxic to insects but is widely used to dilute inflammable fumigants to reduce fire hazards. Carbon tetrachloride is very toxic to humans, causing severe liver damage.

Chloropicrin (CCl_3NO_2). This highly toxic material developed in World War I as a "tear gas" is frequently added in small proportions (2 to 5 percent) to hydrogen cyanide or methyl bromide as a warning agent. It is used as a soil fumigant, less commonly in general fumigation because of its persisting vapors.

Ethylene Dibromide ($CH_2Br\text{-}CH_2Br$). This gas is used in agriculture and as an ingredient in grain fumigant mixtures. It may also be used in termite work as a soil fumigant or as a spot fumigant in grain mills.

Ethylene Oxide ($(CH_2)_2O$. Ethylene oxide is widely used in grain and food fumigation, both to control insects and to prevent microbial spoilage, especially in dried fruits. It is highly inflammable and explosive and is often sold as 1:9 carbon dioxide mixtures. Aerosol bombs with this mixture are now used to sterilize instruments, bedding, and clothing, placed in plastic bags or drum fumigators.

Phosphine (PH_3). Phosphine is a relatively new insecticide which is used in grain fumigation. Special tablets are mixed with the grain as it is stored. These tablets react with the moisture in the grain to produce the toxic phosphine and ammonium carbamate gases which kill grain insects.

Sulfuryl Fluoride (SO_2F_2). This recently developed fumigant is a possible substitute for methyl bromide in household and other fumigations. It may also be useful in drywood termite control.

Sulphur Dioxide (SO_2). This old fashioned fumigant, which was generated for years by burning sulphur candles, is now available in metal cylinders. It does not penetrate well, tarnishes metals, and bleaches some materials. It will kill bed bugs but is less effective than many other insecticides.

DESICCANTS OR SORPTIVE DUSTS

Very finely powdered silica gels and silica aerogels have been tested for the control of cockroaches, fleas, kissing bugs, and ectoparasites of domestic animals such as ticks, lice, and mites (Tarshis, 1959). These compounds kill by removing the outer, waterproof layer of the arthropod exoskeleton, the epicuticle, either by adsorbing the fatty material or by abrasion. The insects lose liquids rapidly, sometimes being incapacitated in an hour's time, and die by desiccation. These materials are reported to be nontoxic to man and to warm-blooded animals. Sorptive dusts are amorphous rather than crystalline compounds, so they do not cause silicosis. Since the action of the dusts is physical rather than chemical, it is possible that insects will not become resistant to them. The real problem in using this type of control

is to keep the fine powder in areas where insects will come in contact with it.

REPELLENTS AND IMPREGNANTS

Repellents are those substances which produce avoidance reactions in animals. A good repellent should (1) give protection for several hours, even under unfavorable atmospheric conditions, (2) be non-toxic and non-irritating to the skin, (3) have no unpleasant odor, (4) be harmless to clothing and accessories such as plastic watch covers, (5) be effective against a wide variety of pestiferous arthropods, and (6) be generally available at reasonably low prices.

Repellents are used especially in situations where residual and space spraying are not feasible. In ordinary civilian life, repellents add greatly to the pleasure of camping, hunting, fishing, and hiking in areas that are not normally treated with insecticides. The military has an even greater interest in repellents since modern warfare and routine operations are carried out in vast areas in which control operations are impossible or economically not feasible.

Repellents applied to the skin. Finely powdered sulfur is one of the oldest repellents which is still generally used, particularly applied to skin or clothing for the control of chiggers. Before World War II there were four standard repellents for use against biting arthropods: oil of citronella, dimethyl phthalate, Indalone, and Rutgers 612. At the beginning of World War II, the last three compounds were combined into a mixture designated 6-2-2 which was used as the standard, all-purpose military repellent. It was composed of 6 parts of dimethyl phthalate, 2 parts Indalone, and 2 parts of Rutgers 612. Between 1941 and 1952 some 10,000 chemicals were screened as mosquito repellents at the Orlando, Florida laboratory of the U. S. Department of Agriculture and the research has continued with the development of deet or diethyl toluamide as one of the most promising, all-purpose repellents at the present time (Gilbert, *et al.*, 1957). More recent studies indicate that two other preparations are effective all-purpose repellents. The standard military skin repellents may be available to civilians in a national emergency and are listed below:

M-2020

4 parts of dimethyl phthalate
3 parts of Rutgers 612
3 parts of dimethyl carbamate

M-2043

4 parts of dimethyl phthalate
3 parts of Rutgers 612
3 parts N, N-diethyl-succinamate

Much of this information has been summarized by King (1951, 1954), the U. S. Department of Agriculture (1955), Dethier (1947, 1956), or Shambaugh, *et al.* (1957).

When properly applied to the neck, face, and both hands, about 12 drops of these liquid repellents will give protection for 2 hours to half a day depending on the person and the species and abundance of the biting arthropods. These repellents can also be sprayed on clothes with aerosol bombs, or hand or power equipment. Many repellents are solvents of paints, varnishes, plastics such as watch crystals, rayon fabrics, and fountain pens. Diethyl toluamide will not affect nylon. Care should be taken not to apply these repellents to the eyes, lips, or other mucous membranes.

Goodhue and Howell (1960) have summarized much of the information regarding other groups of repellents used primarily against flies and cockroaches. Their research indicates that a number of proprietary compounds may have future use in vector or pest control. Research on biting flies which are pests of livestock indicated that emulsions containing pyrethrum, piperonyl butoxide, and an emulsifier would give protection for 2 to 3 days agains biting flies and even longer for ticks, lice, and mites. Table 2.7 summarizes some of the various compounds which are available as repellents of man-biting arthropods.

Repellents applied to clothing (impregnants). During World War II many compounds were tested as clothing impregnants in an effort to find materials that were repellent to chiggers which transmitted scrub typhus in the Pacific area and that would withstand laundering. These chemicals

include benzyl benzoate, mixtures of benzyl benzoate and dibutyl phthalate, and benzil. During the Korean conflict additional research was conducted on clothing impregnants because of the possibility that chiggers, mites, or fleas might transmit epidemic hemorrhagic fever. These studies lead to the development of the present standard military clothing repellent, M-1960 which consists of:

N-butylacetanilide. . . . . 30 percent
benzyl benzoate . . . . . 30 percent
2-butyl-2-ethyl-1, 3-propanediol . . 30 percent

with an emulsifier Tween 80. Directions for treating clothing to make it repellent for about a week are given in the Circular 977 of the U. S. Department of Agriculture (1955).

TABLE 2.7 EFFECTIVENESS OF SELECTED REPELLENTS
(Modified from U. S. Dept. Agri., 1955)

	For Protection Against				
	Mosquitoes	Ticks	Fleas	Chiggers	Black Flies
Diethyl Toluamide (Deet)	X	X	X	X	X
Indalone	X	X	–	–	X
Dimethyl phthalate	X	–	X	X	X
Rutgers 612	X	–	–	X	X
Benzyl benzoate	–	–	X	X	–
Diphenyl carbonate	–	–	–	X	–
Dibutyl phthalate	–	–	–	X	–
6-2-2 mixture	X	X	X	X	X
Sulfur	–	–	–	X	–

ATTRACTANTS

Attractants are materials utilized to lure insects into traps and to induce them to eat poisoned baits. A good discussion of attractants, or attrahents, is given by Dethier (1947, 1956). He reported that natural odors and scents played an important role in the life of insects, particularly with regard to

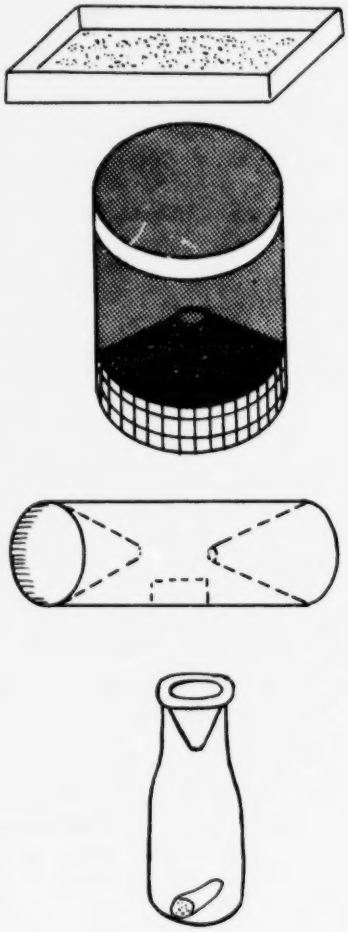
1. Food selection,
2. Oviposition choice, and
3. Sexual attraction.

All of these attractants are of natural origin and in most cases are chemical mixtures. Only a few attractants have been critically analyzed and synthesized commercially. Classic examples are the Japanese beetle attractants, eugenol and geraniol; the female sex attractant of the gypsy moth, hydroxyacetoxylhexadecone; or the protein hydrolyzate with malathion recently used as a poison bait to eradicate the Mediterranean fruit fly in Florida.

In the field of public health, attractants have several practical applications as follows:

1. **To lure insects to poison baits.** Food type attractants in poison baits include sugar as an attractant and selected organophosphorus compounds as toxicants to kill flies, ants and cockroaches; thallium sulfate-sugar or sodium arsenite-sugar baits for ants; and phosphorus paste for cockroaches.

2. **To sample local populations.** Mixed garbage, the natural food or oviposition media of many flies, is a standard bait in many fly traps. Sometimes, beer-molasses mixtures are used to attract house flies, and decaying fish or meat is used to attract blow flies to fly traps. Dry ice, or carbon dioxide, is often used in special lard-can traps to collect the encephalitis mosquito, *Culex tarsalis*, but does not work as well on many other species.



A simple cockroach trap may be made by placing a piece of banana in a milk bottle with an inverted truncated, paper cone in the mouth. In the tropics, sheets of ordinary bond paper treated with castor oil are used to trap sand flies of the genus *Phlebotomus*.

3. To improve the attractiveness of residual sprays. The addition of 2.5 times as much sugar as toxicant improves the attractiveness and prolongs the effectiveness of residual sprays of many organic phosphorus insecticides used in fly or mosquito control.

4. To lure insects away from dairy barns or dwellings. Some fly traps work on this principle, the odor from the dead insects in the fly trap perhaps having an oviposition attraction.

AUXILIARIES

Auxiliaries, in this context, are materials that enhance the effectiveness of basic insecticidal chemicals by altering their physical or chemical characteristics.

SOLVENTS

A solvent dissolves the basic chemical, converting it from a solid to a liquid with the molecules of insecticide evenly dispersed through the resultant solution. The solvent acts both as a carrier for the chemical and as a diluent, reducing the concentration of the insecticide to the most effective and economical percentage. Some solvents, such as petroleum oils, also add to the insect killing powers of the formulation.

Many insecticides are dissolved in solvents such as fuel oil, kerosene, or xylene and applied as solutions or emulsions. The selection of a solvent depends on its ability to hold the insecticide in solution at ordinary temperatures, its toxicity to animal and plant life, its odor and staining characteristics, and its fire hazard. Two general types of solvents are commonly used: (1) volatile solvents, such as xylene, which evaporate after spraying and leave a residual deposit of the insecticide, and (2) nonvolatile solvents, such as petroleum oil, which leave the surface coated with a solution of the toxicant. Fuel oil and kerosene do not dissolve much more than 5 to 8 percent of DDT and many other synthetic insecticides, so other compounds listed in table 2.5 are often used as auxiliary solvents in making concentrates.

The flash point is an important consideration when selecting an insecticide for fogging operations. Materials with a low flash point increase the fire hazard. Therefore, several chemicals are listed in table 2.5 with flash points over 200° F.

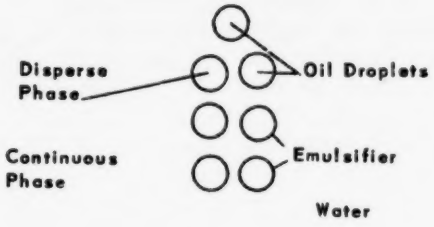
EMULSIFIERS

An emulsifier is a surface active agent that stabilizes a mixture of a liquid within a liquid, milk for example. Thus a technical grade insecticide may be dissolved in a solvent such as xylene and an emulsifier added to produce a concentrate of low bulk that may be stored and moved with ease. Before use the concentrate is diluted with water, the most universal and economical carrier, to produce an inexpensive and effective emulsion.

The emulsifier forms a tough film around each

droplet of oil which resists the tendency of the droplets to coalesce and separate into continuous layers of oil and water. In the familiar oil-in-water insecticidal emulsions, the many finely divided oil droplets form **the disperse phase** and water, **the continuous phase.**

The early emulsifiers were soaps, but modern usage requires synthetic detergents such as the Tritons, Spans, and Tweens. Any substances which lowers the surface tension of water will tend to stabilize a water emulsion.



Oil-in-Water Insecticidal Emulsion (Diagrammatic)

SPREADING AND WETTING AGENTS

Many of the synthetics developed as emulsifiers and detergents are used as wetting and spreading agents. These compounds are rather difficult to separate except in the manner in which they are used. Detergents are developed primarily for their cleansing ability. Spreading agents, such as Hercules Triton B-1956, may be added to oil larvicides to decrease the surface tension and cause the oil to spread in a thinner film on the water surface.

Wetting agents aid in the formation of a continuous film of insecticide on water-repellent surfaces, or increase the rate with which water soaks into or wets solid material. Sulfonated oils, the higher sodium alkyl sulfates, and other surface-active agents are used as wetting agents. Some of these materials, called dispersants, may be added to insecticidal dusts to produce water-wettable insecticide powders (also known as water-dispersible powders) which form suspensions when added to water.

ADHESIVES OR STICKERS

Adhesives are materials added to liquid sprays to improve the retention of the deposit, particularly with regard to the leaching by the rain. Probably the most widely used stickers today are petroleum white oil and fish oil which are used in conjunction with various sprays on orchard and truck crops. Protective materials, such as gelatin, glue, rosin, and other gums are valuable adhesives.

PERFUMES AND MASKING AGENTS

Perfumes or masking agents are agreeable scents like oil of wintergreen added to household insecticides to mask unpleasant odors such as those of pyrethrum or cyclohexanone. There are many proprietary perfumes and masking agents now available.

SYNERGISTS

Synergism (from the Greek meaning "working together") is said to occur when two materials give greater physiological action when applied together than when acting separately. Certain compounds added to insecticidal mixtures so increase their toxicity that the amount of insecticide may be greatly reduced. For example, the addition of the relatively inexpensive synergist piperonyl butoxide to fly and mosquito sprays makes it possible to reduce the amount of the more expensive pyrethrum insecticide and still obtain effective control, with substantial savings in the final formulation. These synergists may also be used to counteract the resistance of insects to certain chemicals. A synergist apparently brings about an alteration in the insect that will predispose it to poisoning. A synergist applied as much as a day before the insecticide will still produce an activating effect. However, a synergist applied after the insecticide is of no value. It is most practicable to mix the synergist with the insecticide.

Many synergists, such as piperonyl butoxide, MGK 264, sulfoxide, and sesamin, are now used in fly and mosquito control, particularly in aerosol bombs and space-spraying formulations. Certain low-toxicity insecticides act synergistically to increase the kill of other more potent compounds, examples being DMC-DDT or perthane-malathion formulations.

CARRIERS AND DILUENTS FOR DUSTS

Insecticidal dusts are sold in concentrations ready for use, but are often diluted for special purposes. Some of the generally available carriers include attapulgite, bentonite, calcite, diatomite,

gypsum, hydrated lime, kaolin clay, pyrophyllite, sulfur, and talc. Dust carriers should be relatively low in cost and must have great adsorptive capacity when they are used to adsorb liquid insecticides such as chlordane. These carriers must be mixed intimately with the toxicant without producing any breakdown of the chemical. Dusts are usually mixed in a ball-mill or other type of blending machine. They must be extremely fine particles and of low density in order that they may be airborne for a considerable distance. Particle sizes of dusts are listed below following the definitions of Haller (1954):

Coarse dust	–	175 microns or larger
Medium dust	–	45-175 microns
Fine dust	–	45 microns or less

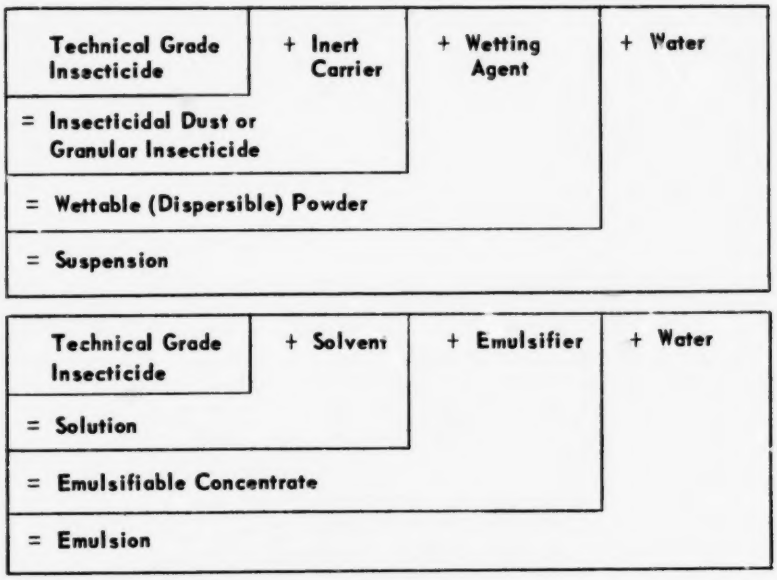
(a micron is only 1/25,000 of an inch, or 1/1000 of a millimeter)

TYPES OF INSECTICIDAL FORMULATIONS

Few insecticides are suitable for use in their pure state. Technical grade insecticides must be made into proper strength dusts, granules, suspensions, solutions, or emulsions before application. Dusts are often diluted to lower concentrations with talc or pyrophyllite. Wettable powders are mixed with water to form suspensions of desired concentration. Liquid sprays are often purchased as concentrated solutions or emulsifiable concentrates. Concentrated solutions may be diluted with oils, and emulsifiable concentrates with water, to prepare field strength solutions of emulsions. The diagrams below indicate graphically the inter-relationships between these various formulations.

Technical Grade Insecticides. Technical grade insecticide is the basic toxic agent in its purest commercial form. It is rarely chemically pure. Technical grade DDT, for example, contains about 70 percent of the isomer which has the greatest insecticidal activity. Technical grade insecticide is, in most cases, mixed with a carrier before use, forming a dust, granule, suspension, solution, or emulsion.

Insecticidal Dusts. Many insecticidal dusts consist of an inert carrier, such as pyrophyllite, with each minute particle coated with a chemical toxic to insects. Others, such as sulfur dusts, are merely finely pulverized insecticides. Dusts may be applied by hand, by simple dust guns, or by large power dusters. These materials are usually low in cost, easy to apply, non-staining, and non-toxic to vegetation. Poisons in dust form are not generally absorbed through the skin of man but may



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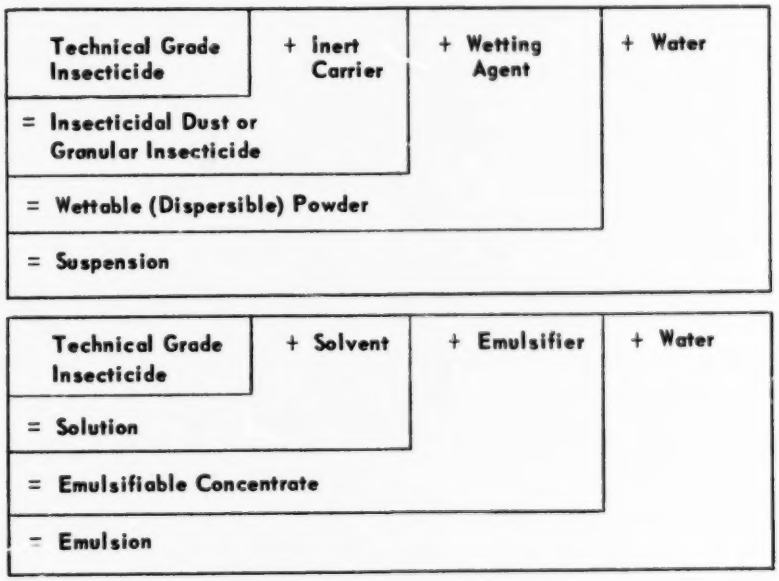

be dangerous if inhaled into the respiratory passages. Dusts do not adhere well to vertical surfaces, and are easily removed by rain and wind. They are unsightly in the home and have been replaced, for the most part, by sprays and aerosols.

Wettable Powder. A wettable powder consists of an insecticide, an inert carrier, and a wetting agent. Most of the important synthetic insecticides, such as DDT, BHC, dieldrin, and malathion, are available as wettable powders. Wettable powders contain a relatively high percentage (15 to 90 percent) of the insecticide in order to avoid whitewashing treated surfaces and masking the active ingredient. The particle size of wettable powders should be very fine in order to form a suitable suspension and prevent clogging of the nozzles and screens. More important, however, Hadaway and Barlow (in Buxton, 1952) stated that there is an inverse relationship between particle size and effectiveness of DDT against mosquitoes and tsetse flies. Particles below 20 microns in diameter are picked up by insects more readily and are less easily detached than larger sized formulations.

Suspension. A suspension consists of a wettable powder mixed with water, so that the fine particles are suspended in water rather than dissolved in a solvent to form a solution. Suspensions require frequent agitation to prevent the solid particles from settling to the bottom of a sprayer. Suspensions are usually sprayed in more dilute form than solutions in order to prevent clogging of nozzles. They are safer to apply than solutions and emulsions, as most suspensions are not absorbed through the skin and will not cause serious burning of plant foliage. Suspensions have less odor than solutions or emulsions due to the absence of a solvent. They are especially valuable for treating outbuildings, adobe, concrete, and thatch structures, because (while the water in the suspensions soaks into these porous structures) the insecticide remains as a deposit on the surface where it can be in contact, and kill, the insects. With emulsions and solutions, on the other hand, the solvents tend to penetrate the porous materials and carry the dissolved insecticide beneath the surface so that it does not come in contact with the insects.

Oil Solutions. Most of the new synthetic insecticides are soluble in kerosene and other organic solvents. The insect cuticle (outer covering) is easily wetted and permeated by oils, making oil solutions of toxic chemicals effective as contact insecticides. In residual spraying the solvent evaporates from treated surfaces, leaving a deposit of the insecticide in relatively pure form. DDT deposits cause a "blooming" of fine crystals that are readily picked up by the feet and bodies of insects. Some formulations crystallize slowly, remaining in saturated solution form on treated surfaces for considerable periods of time. Other products, such as chlordane, may not crystallize, but form a thin film of insecticide on treated surfaces.

Emulsions. Emulsions are similar to solutions in their effect upon insects. Most insecticidal emulsions are first prepared as emulsifiable concentrates with a high percentage of active ingredient. The technical grade insecticide is dissolved in a highly efficient solvent such as commercial grade xylene. An emulsifying agent like Triton X-155 is added to the concentrated solution, forming an **emulsifiable concentrate.** This concentrated material may then be shipped economically to the point where it will be used. It is diluted with water to form an emulsion with the desired percentage of active ingredient. Emulsions or solutions diluted to field strength are called "finished sprays."

Emulsions and solutions are used for most residual spraying indoors and outdoors. They do not stain walls or damage dry paint unless they are improperly formulated, stored, or utilized. They may be toxic to plants and must not be applied to humans or domestic animals as the poison ingredients will be absorbed through the skin. The recommended dosage for space spraying is low enough to prevent toxicity to humans and other mammals.

Aerosols. An insecticidal aerosol is a fine spray with a droplet size between 0.1 and 50 microns in diameter, and with 80 percent of the material, by weight, in particles less than 30 microns in diameter (Yeomans 1952). Haller (1954) gives the particle size of aerosols, sprays and smokes as follows:

Coarse spray	400	microns or larger	
Fine spray	100	–	400 microns
Mist	50	–	100 microns
Aerosols and fogs	0.1	–	50 microns

Fumes and smokes	0.001	–	0.1 microns
Vapors, less than	0.001	–	microns

1 micron = 1/25,000 inch

The finer aerosols remain suspended in the air for some time, killing insects by contact. They may be generated (1) by heat and the shearing action of hot gases as in the Tifa, (2) by steam as in the See-Fog, (3) by an air blast as in hand mist guns, or (4) by the conversion of a chemical expanding into gaseous state as in the aerosol applicator (bomb). Droplets of 10 to 30 microns diameter appear to give the best control for outdoor applications against mosquitoes, (American Mosquito Control Association 1954). Aerosols are not suitable for residual applications, their chief value being in space spraying.

Aerosols are employed in industrial structures for controlling insects by contact or applying a light deposit of insecticide on exposed horizontal surfaces. About 95 percent of an aerosol settles on horizontal surfaces, the remaining 5 percent on walls and ceilings. An aerosol with small particles will give the best dispersion and penetrate into small crevices if applied in closed structures. As a general rule, a 15-minute exposure is sufficient with an aerosol as most of the particles will settle by that time. This type of application is satisfactory for flying insects. Yeomans (1952) lists the following formulations and dosages:

1 pound of technical DDT dissolved in 7½ pints of Sovacide 554C (Socony Vacuum) to make 1 gallon, applied at the rate of 1 gallon per 100,000 cubic feet.

1¼ pounds of technical DDT and ¼ pound of lindane dissolved in 3 quarts of tetrachloroethylene plus 1 pint of SAE 50 motor oil to make 1 gallon, applied at the rate of 2 quarts per 100,000 cubic feet.

1 quart of synergized pyrethrum (1-10 mixture of pyrethrins and a synergist) plus 3 quarts of deodorized kerosene and 4 quarts of tetrachloroethylene (proportions of last two materials can be varied to regulate the particle size), applied at the rate of ½ to 3 gallons per 100,000 cubic feet, depending on the insects involved.

To prevent explosion hazard, aerosols containing oils should not be applied at rates that will give more than 2 gallons of these solvents per 100,000 cubic feet, and they should not be released near an open flame. All work indoors should be done while wearing a proper respirator. The pyrethrum formula is recommended for use around warehoused foodstuffs.

Smokes. Smokes are clouds of insecticidal particles produced by heat. Particle size is less than one-tenth micron. Smokes are similar to aerosols in their uses and properties, but of lesser value for most applications.

PREPARING INSECTICIDES FOR USE

Dusts are usually purchased ready to use but may also be diluted with a number of inert carriers. Table 2.8 shows the proportions by which a dust may be diluted from concentrations as high as 75 percent to dilutions as low as 0.5 percent. In this table, the first number indicates the amount of concentrate and the second number indicates the amount of diluent to use. For example, a 1:4 dilution of 75 percent DDT dust would require that one pound of 75 percent DDT dust be added to four pounds of talc or other diluent to produce five pounds of 15 percent dust.

SOLUTIONS AND EMULSIFIABLE CONCENTRATES

Technical grade insecticides and the solvents in which they are mixed do not usually have the same specific gravity or weight per gallon. They cannot, therefore, be mixed according to volume, but must be prepared on the weight to weight basis, but may be further diluted by volume, with sufficient accuracy, as the specific gravity of the ingredients has been compensated for in the original concentrate. Chlordane, for example, weighs twice as much as kerosene. A solution containing 2 gallons of technical chlordane and 98 gallons of kerosene would contain 4 percent of chlordane by weight, not 2 percent. A chlordane 20 percent concentrate contains 20 percent chlordane by weight. Therefore, it may be diluted by volume 1:9 to to produce a 2 percent finished spray.

DILUTION FORMULAS FOR CONCENTRATED LIQUIDS AND DUSTS

Liquid sprays are often purchased as concentrated solutions or emulsifiable concentrates.

TABLE 2.8 DILUTION TABLE FOR LIQUID CONCENTRATES OR DUSTS

Strength of Finished Spray or Dust	Strength of Concentrate					
	75%	50%	35%	30%	25%	20%
15%	1:4	1:2-1/3	1:1-1/3	1:1	1:2/3	1:1/3
10%	1:6-1/2	1:4	1:2-1/2	1:2	1:1-1/2	1:1
7.5%	1:9	1:5-2/3	1:3-2/3	1:3	1:2-1/3	1:1-2/3
6%	1:11-1/2	1:7-1/3	1:4-5/6	1:4	1:3-1/6	1:2-1/3
5%	1:14	1:9	1:6	1:5	1:4	1:3
2.5%	1:29	1:19	1:13	1:11	1:9	1:7
2%	1:36-1/2	1:24	1:16-1/2	1:14	1:11-1/2	1:9
1%	1:74	1:49	1:34	1:29	1:24	1:19
0.625%	1:119	1:79	1:55	1:47	1:39	1:31
0.5%	1:149	1:99	1:69	1:59	1:49	1:39

Example: Prepare 100 lbs. of 5 percent DDT dust from 50 percent DDT dust and talc. The Dilution Table 2.8 indicates a dilution rate of 1:9, so that there are a total of 10 parts in the desired 100 lbs. of finished formulation. Therefore:

$$\frac{100 \text{ lbs.}}{10 \text{ parts}} \quad \text{each part equals 10 lbs.}$$

With the 1:9 ratio mix 10 lbs. (1 part x 10 lbs.) of the 50 percent DDT dust with 90 lbs. (9 parts x 10 lbs.) of talc to obtain 100 lbs. (10 parts x 10 lbs.) of the 5 percent dust.

TABLE 2.9 DILUTION TABLE FOR PREPARING SUSPENSIONS FROM WETTABLE POWDERS

Percent Water Wettable	Pounds wettable powder required for 100 gallons of finished spray at percentage levels below				
	0.25	0.5	1.0	2.5	5
75	2.6	5.3	10.7	26.7	53.3
50	4	8	16	40	80
25	8	16	32	80	160

These must be diluted with oil or water to prepare field strength solutions or emulsions. Dusts are often diluted to lower concentrations with talc or pyrophyllite. This requires a mechanical mixer to assure complete blending of the two ingredients. The following formulas may be used for computing dilutions of either liquids or dusts:

Dilution Formula No. 1 (for computing dilution rate)

$$X = \frac{C}{S} - 1$$

X = Number of parts of diluent to add to 1 part of concentrate

C = Concentrate, percent of active ingredient

S = Strength or percent of active ingredient in finished spray or dust

Example: Dilute a 25% lindane emulsifiable concentrate to 0.5% finished spray emulsion

$$X = \frac{25}{0.5} - 1 \qquad X = 50 - 1 \text{ or } 49 \text{ parts (1:49 dilution)}$$

(To prepare 50 gallons of emulsion add 1 gallon of concentrate to 49 gallons of water. See table 2.8 for standard dilution rates.)

Dilution Formula No. 2 (for preparing certain quantity)

"Sac Formula" $Q = \frac{S \times A}{C}$

Q = Quantity of concentrate required in mixture (pounds, gallons, ounces)
S = Strength or percent of active ingredient in the finish dust or spray
A = Amount of finished spray or dust to be prepared (pounds, gallons, or ounces)
C = Concentrate, percent of active ingredient

Example 1: Prepare 100 pounds of 2% chlordane dust using talc and 5% chlordane dust.

$$Q = \frac{2\% \times 100 \text{ lbs.}}{5\%} \qquad Q = 40 \text{ pounds of } 5\% \text{ chlordane dust}$$

(Add 40 pounds of chlordane dust to 100 - 40 or 60 pounds of talc.)

Example 2: Prepare 50 gallons of 1% lindane spray using 25% emulsifiable concentrate and water.

$$Q = \frac{1\% \times 50 \text{ gals.}}{25\%} \qquad Q = 2 \text{ gallons of lindane}$$

(Add 2 gallons of lindane concentrate to water to bring total volume to 50 gallons.)

Example 3: Prepare 1 gallon (128 oz.) of 0.5% diazinon emulsion from 20% diazinon emulsion concentrate and water.

$$Q = \frac{0.5\% \times 128 \text{ oz.}}{20\%} = \frac{64 \text{ oz.}}{20} = 3.4 \text{ oz of } 20\% \text{ diazinon concentrate}$$

(Add sufficient water to 3.4 oz. of 20% diazinon concentrate to make 1 gallon)

Dilution Formula No. 3 (weight to weight formula)

"Sad Sac" Formula

The following formula may be used to prepare a solution or suspension on a w/w (weight to weight) basis using either the technical grade insecticide or a concentrate:

$$Q = \frac{S \times A \times D}{C}$$

Q = Pounds of concentrate to use
S = Strength or percentage of active ingredient in the finished spray
A = Amount in gallons of finished spray
D = Density: Weight of one gallon of diluent
C = Concentrate: Percentage of active ingredient

Example 1: Make up 50 gallons of a 2.5 percent chlordane solution in deodorized kerosene. The kerosene weighs about 6.6 pounds per gallon. Use technical grade chlordane.

$$X = \frac{2.5\% \times 50 \text{ gallons} \times 6.6 \text{ lbs./gal.} = 8.25}{100\%}$$

(To prepare 50 gallons of 2.5 percent chlordane, mix 8.25 pounds of chlordane with sufficient kerosene to reach the 50 gal. mark on the drum or other container used.)

This formula may be used to prepare solutions and suspensions on an accurate basis. After the amount of material to be used has been computed and weighed, place it in a container and make a permanent mark to be used when solutions or suspensions are being prepared by field men. These

men will then be able to mix chemicals by volume without using scales to make measurements each time a tankful of material is to be mixed. An alternate method is to weigh out the chemical such as the 8.25 pounds of technical chlordane in the first example. Measure the chlordane in a graduate in order to determine the actual volume of 8.25 pounds of technical grade material. The formula may then be converted to a volumetric formula for further mixing.

Example 2: Prepare 100 gallons of 2.5% DDT suspension from 50% water-wettable powder and water. How many pounds of 50% water-wettable DDT powder are needed?

$$Q = \frac{2.5\% \times 100 \text{ gallons} \times 8 \text{ lbs./gal.}}{50\%}$$

$Q = 40$ lbs. Place 40 pounds of 50% water-wettable DDT powder in the spray tank and add sufficient water to make 100 gallons.

Dilution Formula No. 4

"Sad Cow" Formula

The following formula may be used to dilute liquid concentrates which are prepared on the basis of pounds of insecticide per gallon.

$$Q = \frac{S \times A \times D}{CO \times W}$$

Q = Quantity of concentrate required in gallons
S = Strength or percentage of active ingredient in the finished spray
A = Amount of spray to be prepared in gallons
D = Density: weight of gallon of diluent, usually water
CO = Concentrate: percentage of active ingredient
W = Weight of the insecticide concentrate in pounds per gallon

Many insecticides are now sold with the label indicating pounds of insecticide per gallon rather than percentage of toxic materials, examples are chlordane - 8 pounds per gallon, or DDT - 4 pounds per gallon. In this case, the weight to weight formula is modified so that the factor CO is considered technical grade insecticide or 100 percent, and a factor W - pounds of insecticide per gallon is added.

Example 1: Prepare 100 gallons of 0.5% DDT emulsion from DDT concentrate containing 4 pounds per gallon. How many gallons of 4 lbs./gal. concentrate are needed assuming water weighs 8 lbs./gal.?

$$Q = \frac{S \times A \times D}{CO \times W}$$

$$Q = \frac{0.5\% \times 100 \text{ gals.}, \times 8 \text{ lbs./gal.}}{100\% \times 4 \text{ lbs./gal.}} =$$

1 gal. of 4 lb./gal. DDT concentrate

Add one gallon of concentrate to sufficient water to make 100 gallons of the final spray material.

PRECAUTIONS IN THE USE OF INSECTICIDES

DUSTS AND POWDERS

1. Avoid excessive inhalation or skin contact when handling, mixing, or applying dusts or powders.
2. Change clothing after each day's operations and bathe thoroughly.
3. Keep poisons in plainly-labelled containers and store them away from food items and out of reach of children and irresponsible persons.

EMULSIFIABLE CONCENTRATES AND CONCENTRATED SOLUTIONS

1. Persons handling concentrates should wear protective clothing, such as insecticide-resistant neoprene-dipped gloves, aprons, goggles, and approved types of respirators.
2. Work in well-ventilated area to avoid inhalation of fumes.
3. Protect the skin from exposure to the chemicals.
4. Wash the skin immediately if it becomes contaminated.
5. Remove contaminated clothing immediately, wash the skin, and put on clean clothing.
6. Wear clean clothing every day.

7. Avoid the fire hazard occasioned by smoking, defective wiring, and open flames when mixing inflammable chemicals.
8. Label all insecticide containers carefully.

DILUTE SPRAYS AND MISTS

1. Protect the skin from wetting with the insecticide. Do not spray into the wind.
2. Wear neoprene-dipped gloves to protect the hands.
3. Wear goggles when spraying organic phosphorus compounds.
4. Wear approved type of respirators when spraying in confined quarters. Wear respirators for outdoor dusting or spraying with organic phosphorus compounds.
5. Change clothing daily, and remove clothing immediately if it becomes contaminated. Wear protective clothing when spraying with dieldrin, aldrin, and organic phosphates.
6. Do not spray animals or plants with insecticides unless you are certain such treatment has been approved by the proper authorities.
7. Check your sprayers daily to make certain that hose connections are tight and valves do not leak.

FIRST AID FOR INTERNAL POISONING

1. Call a physician.
2. If unable to reach physician, call fire department rescue squad.
3. For special information, telephone nearest poison control center.
4. Determine nature of the poison, and select suitable antidote.

PESTICIDE	ANTIDOTE
Aldrin	1
ANTU	1
Arsenic trioxide	1
Barium carbonate	1
BHC	1
Chlordane	1
Cyanide	2*
DDT	1
DDVP	2
Diazinon	2
Dieldrin	1
Dilan	1
Diphacin	2
Endrin	1
Fumarin	3
Heptachlor	1
Lead arsenate	1
Lindane	1
Malathion	2
Methoxychlor	1
Nicotine sulfate	1*,**
Para-dichlorobenzene	1
Parathion	2*
Paris green	1
Pentachlorophenol	1*
Phosphorus	4
Pival	3
PMP	3
Pyrethrum	2
Red squill	2
Ronnel	2
Rotenone	2*
Silica gel	3
Sodium fluoride	1
Strychnine	5
Ten-eighty (1080)	1***
TEPP	2
Thallium sulfate	2
Warfarin	3
Zinc phosphide	4

*also artificial respiration as required; no liquids if unconscious.

**also strong tea or coffee; cold head packs; keep body warm.

***also vinegar (1 teaspoon in glass of water).

5. Apply the antidote:

ANTIDOTE 1: Induce vomiting by finger down throat (if this fails, give 1 tablespoon salt in glass of warm water, and repeat until vomit is clear); then 2 tablespoons epsom

salts or milk of magnesia in water; then plenty of milk and water; keep warm, quiet.

ANTIDOTE 2: Induce vomiting by finger down throat (if this fails, give tablespoon salt in glass of warm water and repeat until vomit is clear); give plenty of milk and water.

ANTIDOTE 3: Take no action until physician arrives as immediate danger is not great.

ANTIDOTE 4: Give copper sulfate (½ teaspoon in glass of water) followed by bicarbonate of soda (½ teaspoon in glass of water); then 1 tablespoon salt in glass of warm water (repeat until vomit is clear); then 2 tablespoons epsom salts in glass of water; large amounts of water; NO MILK.

ANTIDOTE 5: Within 10 minutes of poisoning give 1 tablespoon salt in glass of warm water to induce vomiting (**after 10 minutes do not give salt**), next give 1 teaspoon activated charcoal in ½ glass water; have victim lie down in quiet, dark room; keep body warm.

WEIGHTS AND MEASURES

Weights and measurements for insecticidal concentrations and dosages are expressed in both the metric and the United States systems of units. Most scientific workers use the metric system almost exclusively, or a combination of the two systems, such as "200 milligrams per square foot." It would be more consistent to say "2 grams per square meter." Temperature may be given in either the Fahrenheit or Centigrade scales. Therefore, the following tables are provided to assist the field worker in converting the recommendations from one system to another. The units for each system are not given as they are defined in the dictionary.

WEIGHTS

AVOIRDUPOIS TO METRIC		METRIC TO AVOIRDUPOIS	
1 grain	64.8 milligrams	1 milligram	0.01543 grains
1 ounce	28.35 grams	1 gram	0.03527 ounces
1 pound	453.59 grams	1 kilogram	2.205 pounds
1 short ton	0.91 metric ton	1 metric ton	2205 pounds

LIQUID MEASURE

U. S. UNITS TO METRIC		METRIC TO U. S. UNITS	
1 fluid ounce	29.57 milliliters	1 milliliter	0.0338 ounces
1 pint	0.47 liter	1 liter	2.113 pints
1 quart	0.95 liter	1 liter	1.057 quarts
1 gallon	3.78 liters	1 liter	0.2642 gallons

LINEAR MEASURE

U. S. UNITS TO METRIC		METRIC TO U. S. UNITS	
1 inch	25,400 microns	1 millimeter	0.03937 inches
1 inch	2.54 centimeters	1 centimeter	0.3937 inches
1 foot	30.48 centimeters	1 meter	39.37 inches
1 yard	0.91 meter	1 meter	3.281 feet
1 rod	5.03 meters	1 kilometer	3281 feet
1 mile	1.61 kilometers	1 kilometer	0.6214 mile

AREA MEASURE

U. S. UNITS TO METRIC		METRIC TO U. S. UNITS	
1 square inch	6.45 square centimeters	1 square centimeter	0.155 square inches
1 square foot	929 square centimeters	1 square meter	10.76 square feet
1 square yard	0.836 square meter	1 square meter	1.196 square yards
1 square rod	25.29 square meters	1 hectare	2.471 acres
1 acre	4047 square meters	1 square kilometer	0.3861 square miles
1 square mile	2.59 square kilometers		

CUBIC MEASURE

U.S. Units	Metric	Metric	U.S. Units
1 cubic inch	16.39 cubic centimeters	1 cubic centimeter	0.061 cubic inches
1 cubic foot	28320 cubic centimeters	1 cubic meter	35.31 cubic feet
1 cubic yard	0.7646 cubic meters	1 cubic meter	1.308 cubic yards
		1 cubic meter	264.2 gallons

VOLUMETRIC MEASURE FOR POWDERED INSECTICIDES

Measure	U. S. Unit	Metric Unit
1 teaspoonful	1 1/3 fluid drams	5 cubic centimeters
1 tablespoonful	3 teaspoonsful	15 cubic centimeters
1 fluid ounce	2 tablespoonsful	30 milliliters (liquid measure)
1 cupful	16 tablespoonsful	237 cubic centimeters
1 pint	2 cups or 16 fluid ounces	473 milliliters (liquid measure)

CONVERSIONS TABLES AND EQUIVALENTS

TEMPERATURE

The Centigrade thermometer is so calibrated that the boiling point of water is 100° C and the freezing point 0°. The interval between freezing and boiling is divided into 100 parts or degrees. The Fahrenheit thermometer has the boiling point of water at 212° F. The 0° F point represents the temperature resulting from mixing equal quantities, by weight, of snow and common salt. The freezing point of water is 32° above the zero point on the scale. Temperatures may be converted from one scale to the other by using the following formulas:

Temperature Conversion Formulas

$$°F = (°C \times 9/5) + 32$$
$$°C = (°F - 32) \times 5/9$$

LITERATURE

The literature on insecticides is enormous and is constantly increasing. A short list of general works and significant recent contributions is included in the "Selected References." Current literature on insecticides is published in a wide variety of official publications of Federal and State agencies and in the periodicals listed below.

Periodicals

Annals of Applied Biology
Annual Review of Entomology
Bulletin of the Entomological Society of America
Bulletin of Entomological Research
Contributions from Boyce Thompson Institute
Industrial and Engineering Chemistry
Journal American Society of Tropical Medicine and Hygiene
Journal of Agricultural Science
Journal of Economic Entomology
Journal of Industrial Hygiene and Toxicology
Journal of Pomology and Horticultural Science
Journal of the Association of Official Agricultural Chemists
Journal of the Society of Chemical Industry
Miscellaneous Publications of the Entomological Society of America
Mosquito News
Pest Control
Phytopathology
Soap and Sanitary Chemicals

Abstract Journals and Bibliographies

Bibliography of Agriculture, U. S. Dept. Agriculture Library
Biological Abstracts
Bulletin of Hygiene
Chemical Abstracts
Excerpta Medica, Section on Medical Microbiology, Immunology and Serology, and Section on Public Health
Public Health Engineering Abstracts
Review of Applied Entomology, Series A and B
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